An eco-profile of building materials

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AN ECO-PROFILE OF BUILDING MATERIALS

Thesis presented in candidature for the award
of the degree of Doctor of Philosophy

by

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To the memory of my father and mother

CONTENTS

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Abstract

This research examines the environmental parameters associated with the production and delivery of building materials in the U.K. in 1991. Using primary data supplied from commercial sources, an eco-profile is produced for each material by calculating the gross inputs of energy and raw materials and gross outputs of solid waste, air and water emissions. The production sequences are traced from raw materials in the ground through to the final product and extend to include transport operations and the production and delivery of fuels and ancillary materials.

The results are used to complete eco-profiles for the construction of a three bedroom bungalow house and a four bedroom two storey detached house. It is shown that per square metre of floor space, the construction of the two storey detached house produces considerable reductions in the burdens on the environment.

Eco-profiles are used to compare the environmental burdens associated with alternative building materials. The effect of alternative building materials on the eco-profiles of house construction is discussed. It is shown that significant reductions in the gross inputs and outputs may be made by substituting dense concrete blocks for clay bricks.

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Chapter 1

INTRODUCTION

1.1 Background

Industrial processes may be described as systems characterised by the consumption of energy and raw materials and the production of finished goods and waste material. In the early years of industrialisation when raw materials were considered to be plentiful, it is unlikely that much attention was given to the conservation of energy and mineral resources or to the impact on the environment of waste solids, liquids and gases. As industrialised societies developed, economic considerations alone, rather than environmental pressures forced individual companies to monitor energy consumption and waste production. Little consideration was given to the possible depletion of energy or mineral resources, or to the effect on the environment of toxic or unsightly waste. Indeed, uncontrolled air emissions, discharges to water, and indiscriminate dumping of solid waste were common features of industrial processes until relatively recent times.

The steady rise in the number of industrialised economies, coupled with a growing world population, made increasing demands on the world's finite resources and produced a corresponding increase in waste materials. Worries that continued economic growth could not be sustained indefinitely without a severe depletion of these resources surfaced in the 1960s. These concerns prompted a number of modelling studies[1,2,3] all of which warned that depletion of fossil fuels and scarce materials, together with attendant pollution problems, posed a serious threat to future economic growth and development. Furthermore, it was thought that rising levels of thermal waste energy might cause global warming and subsequent climatological changes. Although these studies were received with some reservations, they stimulated a fresh interest in the efficiencies of industrial processes. Operations such as mineral extraction, fuel production, manufacturing processes, transport and disposal of waste material, hitherto treated as separate unrelated entities, were now considered together for the first time as belonging to *extended industrial systems*. In this context, an *extended industrial system* is defined as one which starts with raw materials in the ground, and incorporates all the separate processes and operations associated with the manufacture and use of a product, up to and including eventual disposal at the end of its useful life.

Since fuel consumption and production rates by individual factories were already closely monitored , the calculation of energy consumption per unit of output was relatively straightforward. Consequently, initial interest in extended industrial systems focused on the use of energy, especially fossil fuels, and the term *energy analysis* was used to describe this work. In order to complete an energy analysis for a given industrial process, it is first necessary to construct flow charts and to calculate mass balances detailing material flows into, across, and out of the production system. Thus, an important consequence of energy analysis investigations was the provision of additional information on raw materials requirements and solid waste emissions.

One of the first attempts at describing the behaviour of extended industrial systems was reported to the World Energy Conference in 1969,[4] and concerned the calculation of the cumulative energy requirements for the production of chemicals. The stimulus provided by the oil shortages in the early 1970s prompted further studies across a range of industrial systems including some of relevance to this work.[5-39] However, interest in energy analysis declined somewhat in the late 1970s as oil supplies were restored and as many countries reduced their dependence on external supplies of fossil fuels by increasing their nuclear capacity.

An increasing awareness of environmental issues became evident in Europe during the 1980s. For example, in 1985 an EC Directive on Liquid Food Containers[40] was passed which compelled member countries to monitor solid waste production as well as the consumption of energy and raw materials, and in 1990 the British Government produced an Environment White Paper[41] setting out Britain's environmental strategy. More recently, in 1994 an EC Directive on Packaging and Packaging Waste[42] was passed which enlarged the provisions of the 1985 Directive on Liquid Food Containers and compelled member states to monitor the production, recovery and recycling of packaging waste and the consumption of raw materials for all packaging materials. During this period the problems of acid rain, the potential for global warming, ozone depletion, and the continuing damage to the marine environment focused international attention on air and water pollutants, and air and water emissions were soon added to energy, raw materials and solid waste considerations.

The calculation of air and water emissions for industrial processes can be made using the methodology already developed for calculating energy consumption and raw materials requirements.[43] Consequently, *energy analysis* evolved to encompass a wider remit and became known by a variety of names such as *resource analysis, resource and environmental profile analysis, cradle to grave analysis, cradle to gate analysis, eco-balance*, *eco-profile*, and *life-cycle analysis*. However, an eco-profile or cradle to gate analysis falls short of a complete life-cycle analysis since it does not include the use or final disposal of the finished product.

1.2 Scope of study

Although energy analysis studies of building materials were reported in the 1970s* and early 1980s,** with the exception of a recent Austrian ecological study comparing materials used in window frame manufacture,[44] a Canadian study comparing gross energy consumption and carbon dioxide emissions during building construction,[45] and a limited Danish study,[46] there has been little published interest since then in extending the work to include waste emissions, and so complete an eco-profile or life-cycle analysis. Further stimulus to research in this field has been provided by the following developments.

- Changes in building regulations, which now emphasise the importance of energy conservation in building design. Consequently, double glazed windows, insulated concrete building blocks, and insulation materials such as expanded polystyrene foam and polyurethane foam, have become standard features of modern house construction.

- The introduction of new materials, such as PVC, which have provided an alternative to traditional building materials such as timber in window frames, cast iron and aluminium in rainwater drainage systems, and metals and clay in underground piping systems.

- Significant quantities of fresh information have appeared recently, providing eco-profiles for the manufacture of the following raw materials used in the

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* See endnotes 8, 11, 12, 13, 14, 15, 16, 17, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31
** See endnotes 32, 34, 35, 36, 37, 38, 39

construction industry: aluminium and steel,[47] thermoplastics such as polyethylene and polypropylene,[48] polystyrene,[49] polyvinylchloride,[50] and polyurethane precursors.[51]

- Likely alterations to the efficiencies of fuel production and delivery, and the energy requirements of transport over the years.

In the light of these developments there is a perceived need to generate new information concerning building materials. The purpose of this research is to satisfy this need, and, by treating building materials as belonging to extended industrial systems, to complete an eco-profile of both new and traditional building materials. Data from commercial sources are to be collected and processed so that a computer model may be constructed. Initially the model will be used to complete eco-profiles for different building materials, but eventually it is intended to pull the separate sets of data together in the final model to complete and compare eco-profiles for the construction of two types of modern building, a three bedroom bungalow house, and a four bedroom two storey detached house. The sensitivity of the final outcome to the use of alternative building materials will also be investigated. The conclusions of this type of research may be of interest and use to architects, builders and others involved in building design and construction.

In constructing eco-profiles it is important to state clearly the limits of the analysis and the elements to be included or excluded. The eco-profiles for the two types of building to be considered in this research have been limited to include only those materials used in the construction of the house shells, and do not include external services such as water supplies and drainage systems beyond the boundaries of the house, or internal fittings such as baths, sinks, wall tiles, kitchen units and electricity cables. Moreover, they are not concerned with the competing aesthetic qualities of the different building materials.

In the following chapters it is proposed to examine life-cycle analysis methodology in detail, and to update both fuel production and delivery efficiencies and the energy requirements of transport, before moving on to complete eco-profiles of different building materials.

Chapter 2

METHODOLOGY

2.1 Overview

The basis of *life-cycle assessment* methodology, upon which much of this chapter relies, has been discussed in detail elsewhere.[52,53] Essentially, there are three separate but inter-related stages to any life-cycle assessment.

1. *The life-cycle inventory*: a catalogue of the inputs of raw materials and energy into an extended system, and the outputs of solid, liquid, and gaseous material from that system.
2. *The life-cycle impact analysis*: an assessment of the environmental impact of the inputs and outputs identified in the inventory stage.
3. *The life-cycle improvement analysis*: an evaluation of ways in which the environmental impacts may be reduced.

The methodology for the preparation of the first stage, the life-cycle inventory, is well understood and has received most attention during the last twenty years. The inventory stage supplies information which may be used to assess the impact on the environment in the second stage, the impact analysis. At present, this stage of life-cycle assessment is less developed as the full effects of environmental releases are unknown or incompletely understood. The final stage, the improvement analysis, is perhaps the most difficult to deal with, since any strategies designed to mitigate environmental releases rely on a full understanding of the interconnecting linkages between the source and the effect. Moreover, although efficiency gains may reduce the overall impact on the environment, it is difficult to selectively reduce the production of any one waste product without producing another.

For example, the removal of gaseous discharges of sulphur dioxide, a precursor of acid rain, from coal burning power stations is only achieved at present by the production of solid waste calcium sulphate and carbon dioxide, a greenhouse gas. In this case a useful product is formed, but this may not always be the case. Since a methodology to deal with the impact and improvement analysis stages is not yet fully developed, this research will focus on the inventory stage of life-cycle assessment.

2.2 Life-cycle inventory

2.2.1 Ideal industrial systems

Life-cycle analysis is based on the concept of a *system* which is defined as a set of operations acting together to perform a defined function. It must be stressed that whilst industry is concerned with products, life-cycle analysis is concerned with systems; however, for those systems producing a single product, such as flat glass manufacture, then the system can be identified with the product.

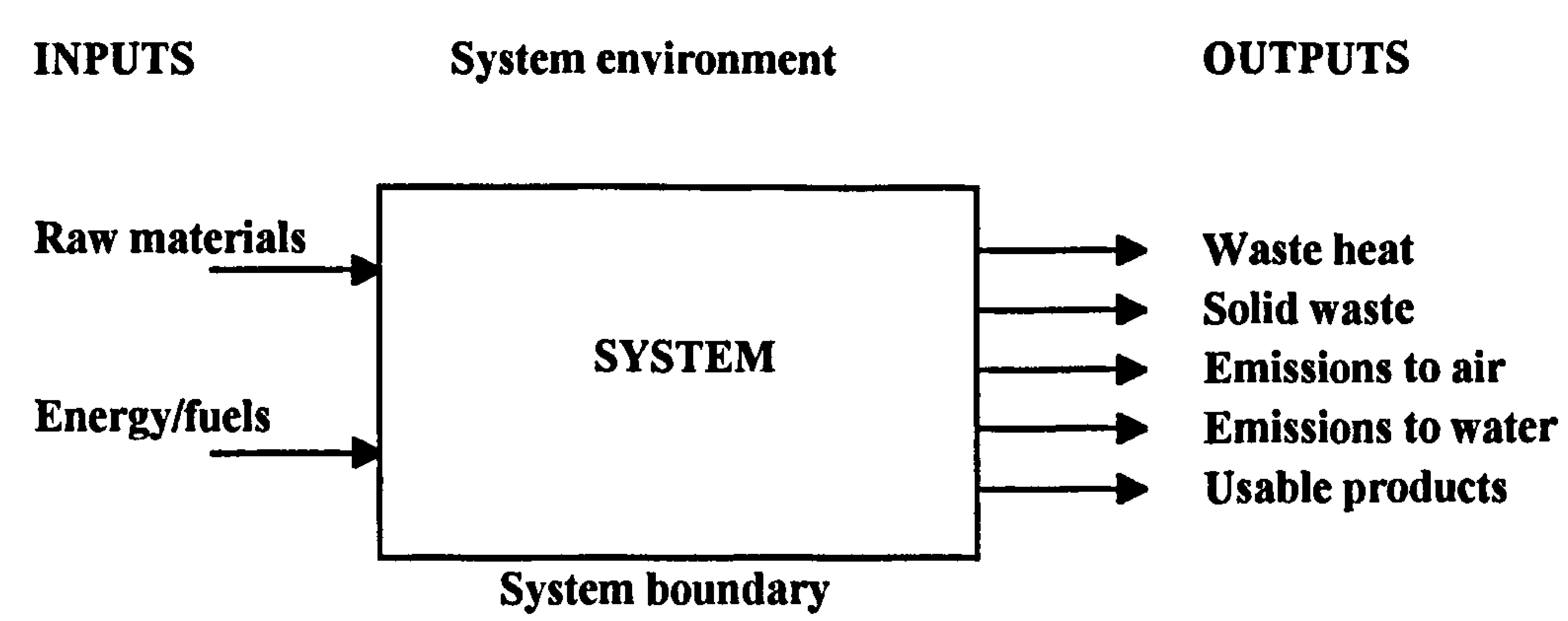


Figure 2.1 Simple industrial system[53]

A schematic representation of a simple industrial system is depicted in Figure 2.1, from which it can be seen that the system boundary acts as an interface between the system and the system environment. The system environment acts both as a source of raw materials and energy inputs, and a sink for outputs of waste energy, waste material, and useful products. Of course in a full life-cycle analysis there is ultimately no useful product, simply waste material. In general, the total energy input to a system will eventually be converted into waste heat, and since the energy input is known, there is no need to monitor this output. The only exception to this generalisation may occur in exothermic or endothermic chemical processes, when energy may be produced or absorbed respectively as a result of chemical interactions. However, since the free energy change of the reaction is usually small in comparison with the total energy input, it may be ignored.

The collection of operations to be included within a system, and the position of the system boundary, is determined by the system function, which must be clearly defined. Sometimes a physical boundary can be identified. For example, a machine producing PVC profiles for use in window frames could be considered as a system if the system boundary was the machine itself. Similarly, the system boundary may be drawn around all the operations in a given factory. However, a physical boundary is not always suitable or easily recognised. For example, it is impossible to construct a physical boundary around systems which include external transport operations, or around complex industrial systems which are broken down and considered as a notional set of sub-systems existing only for the purposes of the analysis.

Although the system itself is of most interest, it is impossible to correctly describe the system without reference to its function, or to compare two systems unless they are serving the same function. For example, it is incorrect and misleading to compare a system designed to produce clay bricks with one producing flat glass. They are different systems with different technologies serving different functions. Moreover, other factors such as age of plant, technology used, and country of manufacture must be stated to complete the system description.

Life-cycle analysis methodology is rooted in thermodynamics and other physical laws of nature rather than economic considerations. Of particular importance are the law of conservation of mass, the law of conversation of energy and thermodynamic sign conventions, which when applied to the analysis of industrial systems may be summarised as follows.

1. *Law of conservation of energy*: the total energy inputs to a system must equal the total energy outputs from that system.
2. *Law of conservation of mass*: the total mass inputs to a system must equal the total mass outputs from that system.
3. *Thermodynamic sign convention*: material and energy flows *into* a system are positive, whilst flows of material and energy *out* of a system are negative.

Strict adherence to thermodynamic sign conventions and the physical laws of nature is essential when constructing energy and mass balances for a system, and failure to apply these rules will invalidate the analysis.

2.2.2 Practical industrial systems

In practice, industrial systems are composed of interdependent sequences of sub-systems obtaining inputs from upstream operations, which in turn produce outputs for the next downstream operation. It is important to note that sub-systems must possess the same characteristics as the larger system to which they belong; that is, their functions must be clearly defined and they must conform to the same physical laws of nature. Many manufacturing systems consist of a linear sequence of sub-systems, whereas extended industrial systems are more likely to consist of non-linear networks of sub-systems. Since extended systems include all operations concerned with the production of fuels and materials they consist of the three main groups of operations shown in Figure 2.2.

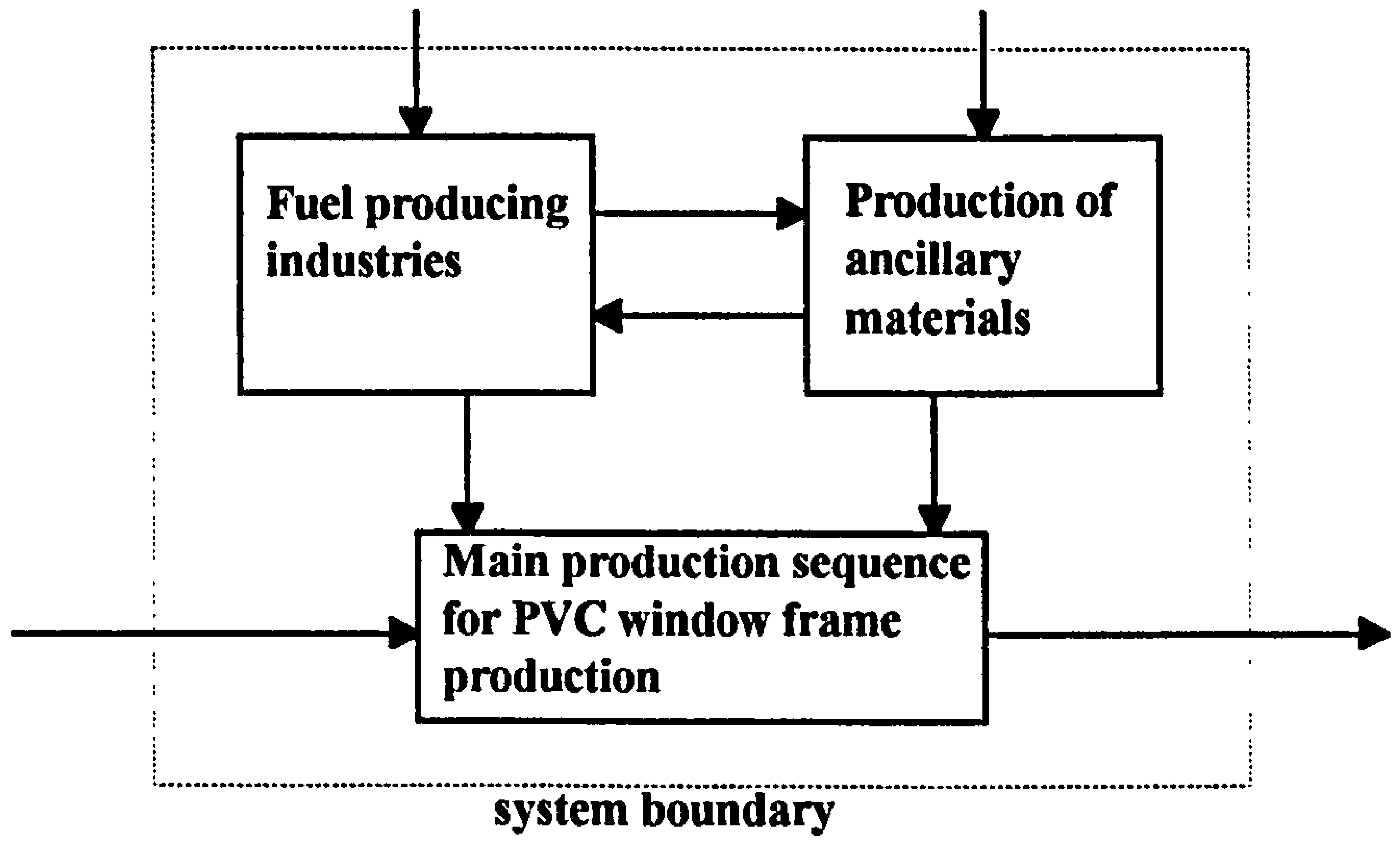


Figure 2.2 Networked groups of operations included in an extended industrial system producing PVC window frames

These operations are the main production sequence, the fuel producing industries, and the supporting ancillary industries. Transport operations pervade most industrial operations and have been excluded for reasons of clarity, not because they are considered unimportant. The main production sequence is usually identified without difficulty. For example, if the extended industrial system is defined as the production of PVC window frames the operations to be included within the main production sequence are the linear sequence of sub-systems depicted in Figure 2.3.

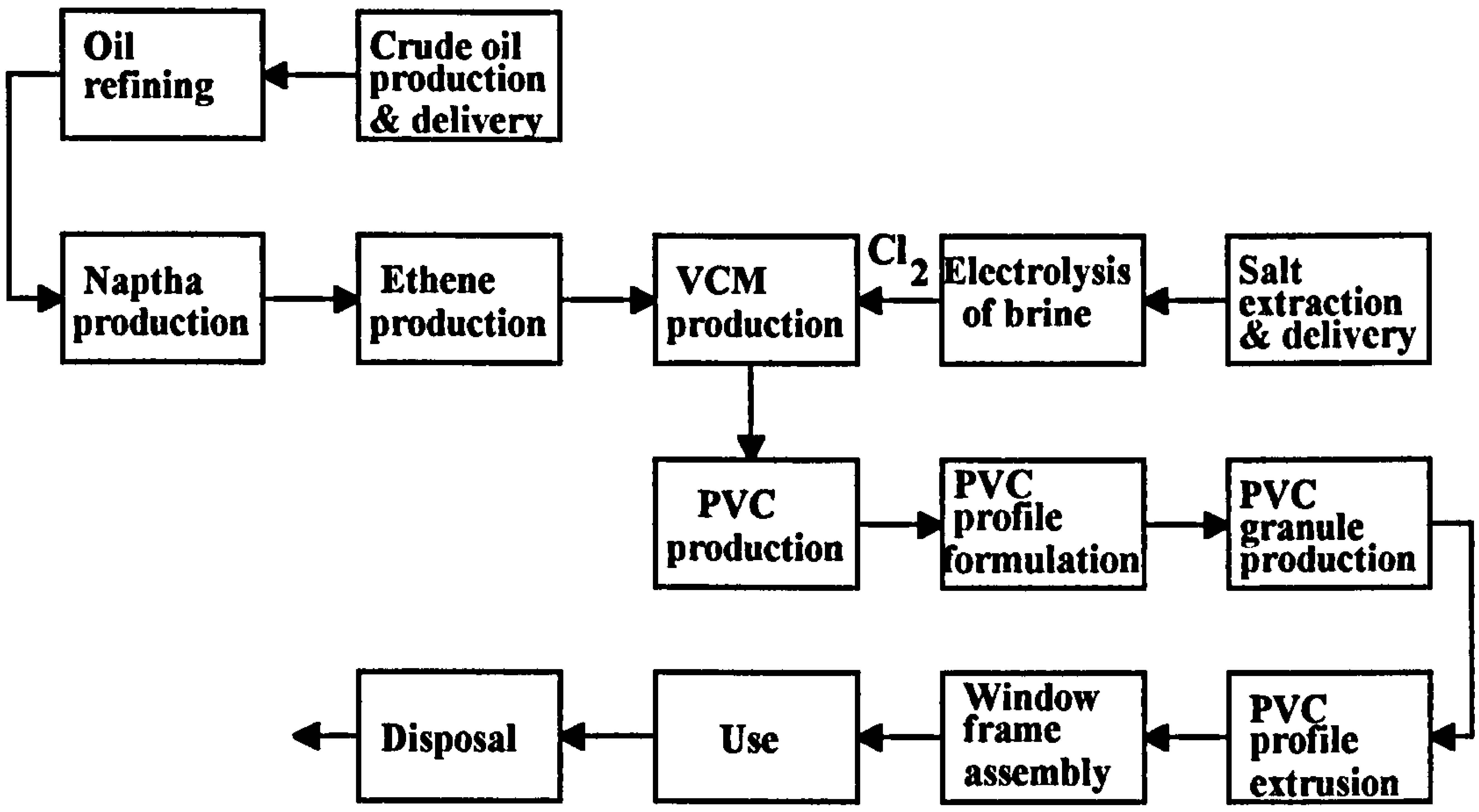


Figure 2.3 Main process sequence for the production and use of PVC window frames

The supporting ancillary industries supply additional materials, which in this example would include steel, PVC formulation additives such as titanium dioxide, chalk and heat stabilisers, labels, pallets and bags. It is interesting to note that if PVC granules, used for the production of PVC profiles, are delivered in bags which are also produced from PVC, as shown by the process route in Figure 2.4, then the packaging of PVC granules makes a further demand on upstream operations producing PVC.

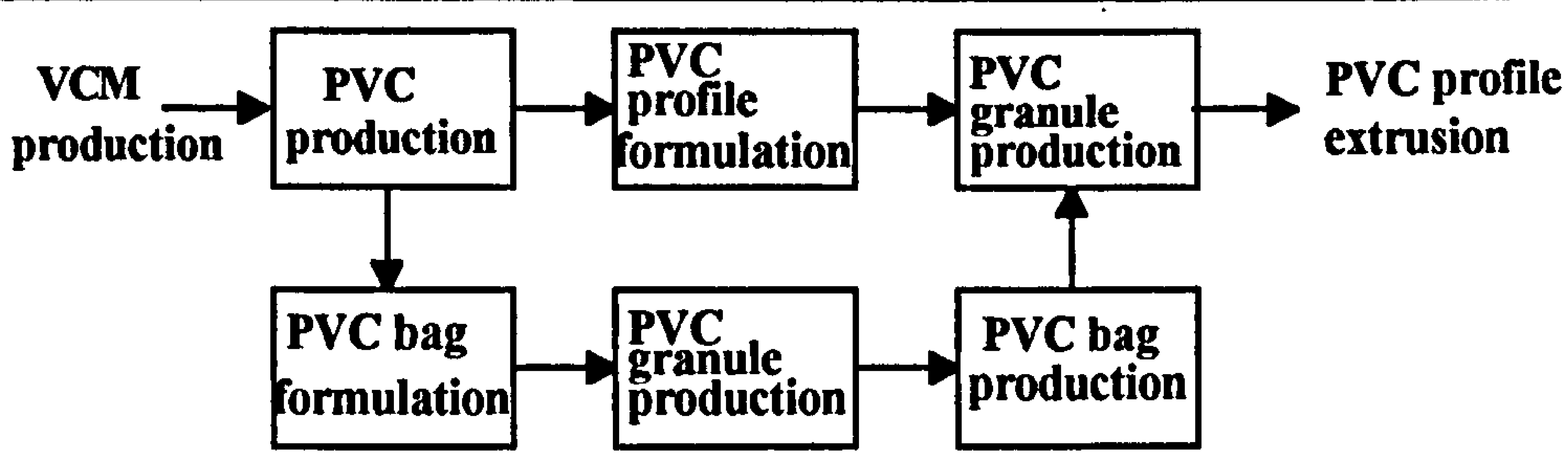


Figure 2.4 Process route for the production of PVC bags

The inputs of ancillary materials are usually collected along with the data for the unit operations in the main process sequence. However, for a complete analysis, the production of ancillary materials must always be traced back to the extraction of raw materials and fuel in the ground. Sometimes such data are unknown or difficult to extract, and it is tempting to ignore these contributions if the inputs are small. However, small inputs may make a significant contribution to the final outcome and their omission may introduce errors. Thus, the case for omission should be proved rather than assumed. Any data omission must be clearly stated in order to avoid any ambiguity.

The fuel producing industries, which will be discussed in more detail in Chapter 3, consist of a non-linear network of sub-systems, each producing fuels such as coal, natural gas, oil fuels, coke and electricity used by the main process route and the production of ancillary materials.

2.2.3 Assessing the system performance

The performance of a system may be considered as a function of the inputs of raw materials and energy, or the outputs of useful products and waste emissions as shown in the idealised simple system of Figure 2.1. The only exception is waste heat production which is rarely monitored, as discussed in Section 2.2.1.

The inputs are of interest to conservationists since they are a measure of the demand on the resources required to sustain the system, whilst the outputs are of use to environmentalists concerned with possible pollution effects. It should be noted that in a full life-cycle analysis all the outputs may be considered as potential pollutants, including useful products at the end of their useful lives.

For any given period of time the rate of flow of materials through the sytem will control the size of the inputs and outputs. To overcome this dependency it is convenient to normalise the system parameters with respect to a physical measure of the flows through the system. For unit industrial operations, mass of usable product is the normal physical measure of system output, but any suitable means such as volume or area may be used. In the fuel producing industries, however, energy output is frequently used.

Thus, for a simple idealised system with total energy input E, producing a mass of usable product M_p, the normalised system energy requirement per unit output is E/M_p. Similarly, if the air, water and solid waste emissions are A, W, and S, respectively, the normalised air, water and solid waste emissions are A/M_p, W/M_p, and S/M_p respectively.

The calculation of system parameters for a system consisting of a linear sequence of idealised sub-systems A, B and C, as depicted in Figure 2.5, is performed in an identical manner. The sequence shows that sub-system A requires an energy input E_1 to process a mass input m_1. In turn, sub-system B consumes an energy input E_2 in processing a mass input m_2. This process is repeated by sub-system C to produce a final mass of usable product m_4. Consider the derivation of the normalised system energy, E_s, as an example. The system energy, E, is the sum of the three separate energy inputs to the three sub-systems A, B, and C. Thus,

$$E = E_1 + E_2 + E_3$$

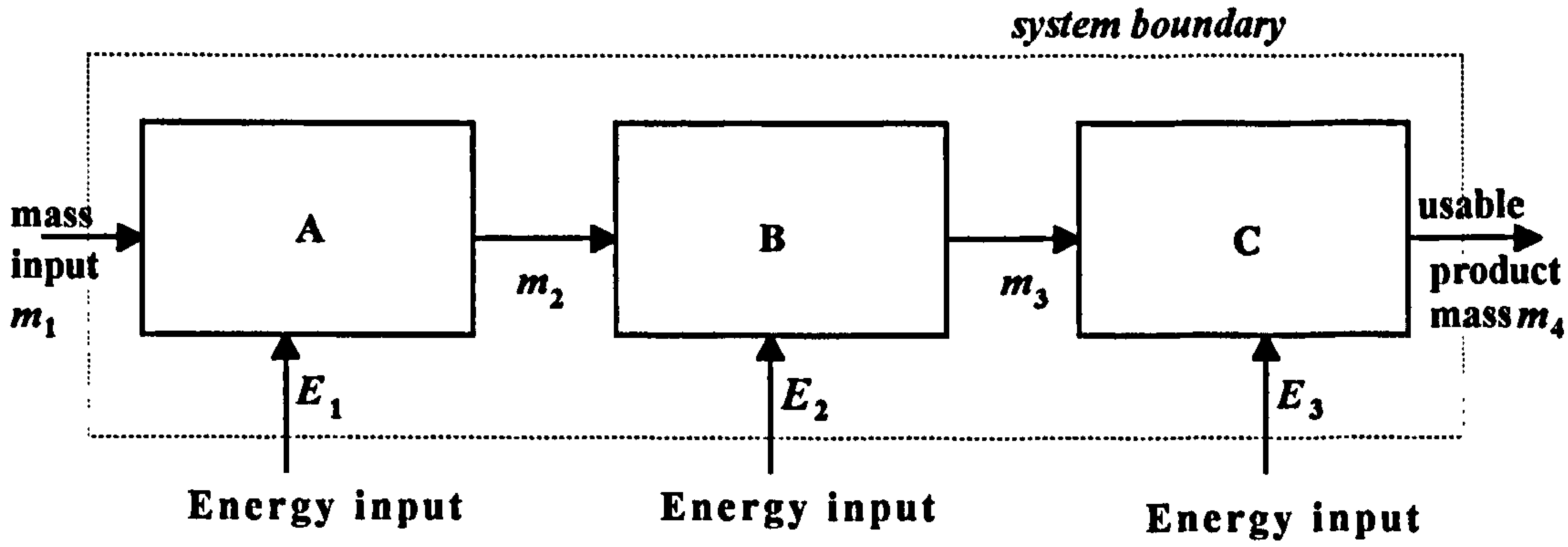


Figure 2.5 A simple linear sequence of idealised sub-systems

and the normalised system energy may be written as

$$E_s = \frac{(E_1 + E_2 + E_3)}{m_4}$$

Whereas linear sequences of operations are frequently used in manufacturing processes, extended industrial systems are more likely to consist of non-linear networks. The calculation of system parameters for such networks can be a very tedious and complex task, and before cheap computing power became readily available it was often convenient to convert such networks into simplified pseudo-linear sequences. Unfortunately, calculations based on pseudo-linear sequences are only approximate and prone to errors. Although calculations associated with networked operations provide more accurate solutions they are more difficult to compute by hand. However, they present little problem for computers, and are solved using the process of iteration, where notional values are first assigned to each operation and the whole system then evaluated. The new calculated values are then substituted for the original values, and the whole system evaluated once again. The revised values are then substituted once more, and the process repeated. This procedure is applied until the calculated values converge to a value within the level of accuracy required, which is typically after about four or five iterations.

The above discussion relates to the production of a single product. However, when more than one product is produced it is necessary to partition or allocate the system parameters between the different products. The various methods of partitioning will be examined in Section 2.2.4.

2.2.4 Partitioning or co-product allocation

As discussed earlier, the inputs to and outputs from a simple industrial system producing a single product can be identified with that product, and the calculation of normalised inputs and outputs for such systems is a relatively simple matter. In contrast, inputs and outputs for systems producing more than one product, are identified with the system, not any one product, and a different procedure must be adopted to analyse such systems. The accepted technique is to consider the system as a series of sub-systems, each producing a single product, all of which, acting together, are equivalent to the original system. A suitable partitioning parameter is then applied to the overall system so that the inputs and outputs can be apportioned to the separate single product sub-systems. The partitioning parameter will vary from one system to another, but must correspond as closely as possible with the physical or chemical processes taking place within the original system. It is important that economic parameters, such as the market value of products, which are subject to external influences of supply and demand, are never used to partition systems based on physical processes. Physical systems are governed by the laws of science and are completely independent of economic considerations.

The basis on which most systems are partitioned is as follows:

- mass - for physical processes when the co-products are materials
- energy - for physical processes when the co-products are fuels
- stoichiometry - for chemical processes.

Nonetheless, it must be noted that for systems in which a specific input is identified with a specific product, it is appropriate to use more than one partitioning parameter. The method of partitioning for each of the above parameters may be understood by considering the following examples.

1. The thermal cracking of naphtha
2. The co-production of coke and manufactured gas from coal,
3. The electrolysis of brine to produce chlorine, hydrogen and sodium hydroxide.

1. The thermal cracking of naphtha

In this example, a naphtha cracker uses an energy input, E, to process a material input of naphtha, mass M, and produce outputs of ethylene, propylene, unspecified other products, and waste material of masses m_1, m_2, m_3, and W respectively, as shown in Figure 2.6.

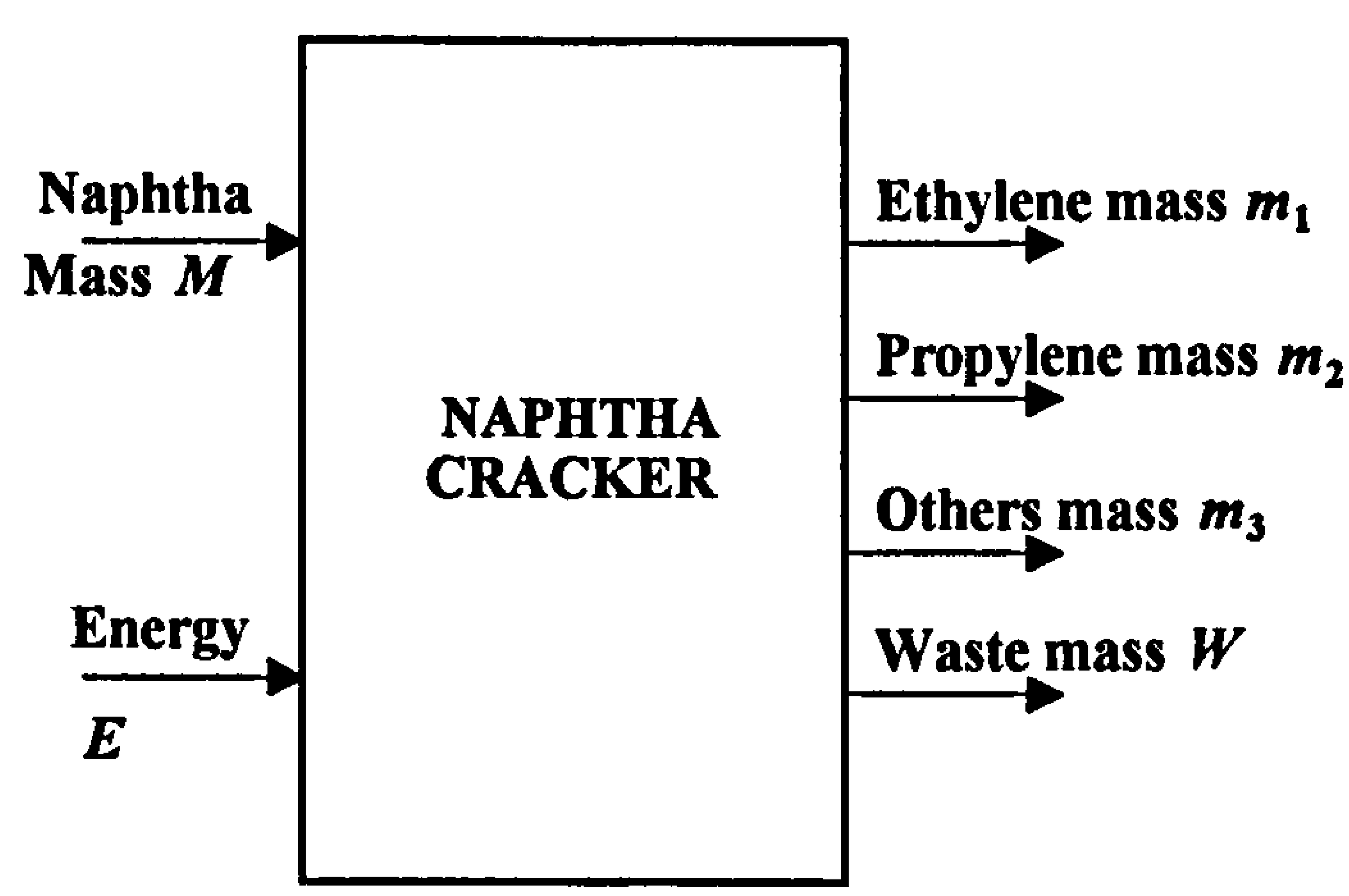


Figure 2.6 Schematic diagram of a naphtha cracker showing inputs and outputs

For the purpose of partitioning, the cracking process may be considered as three separate sub-systems contained within the cracking column, as shown in Figure 2.7.

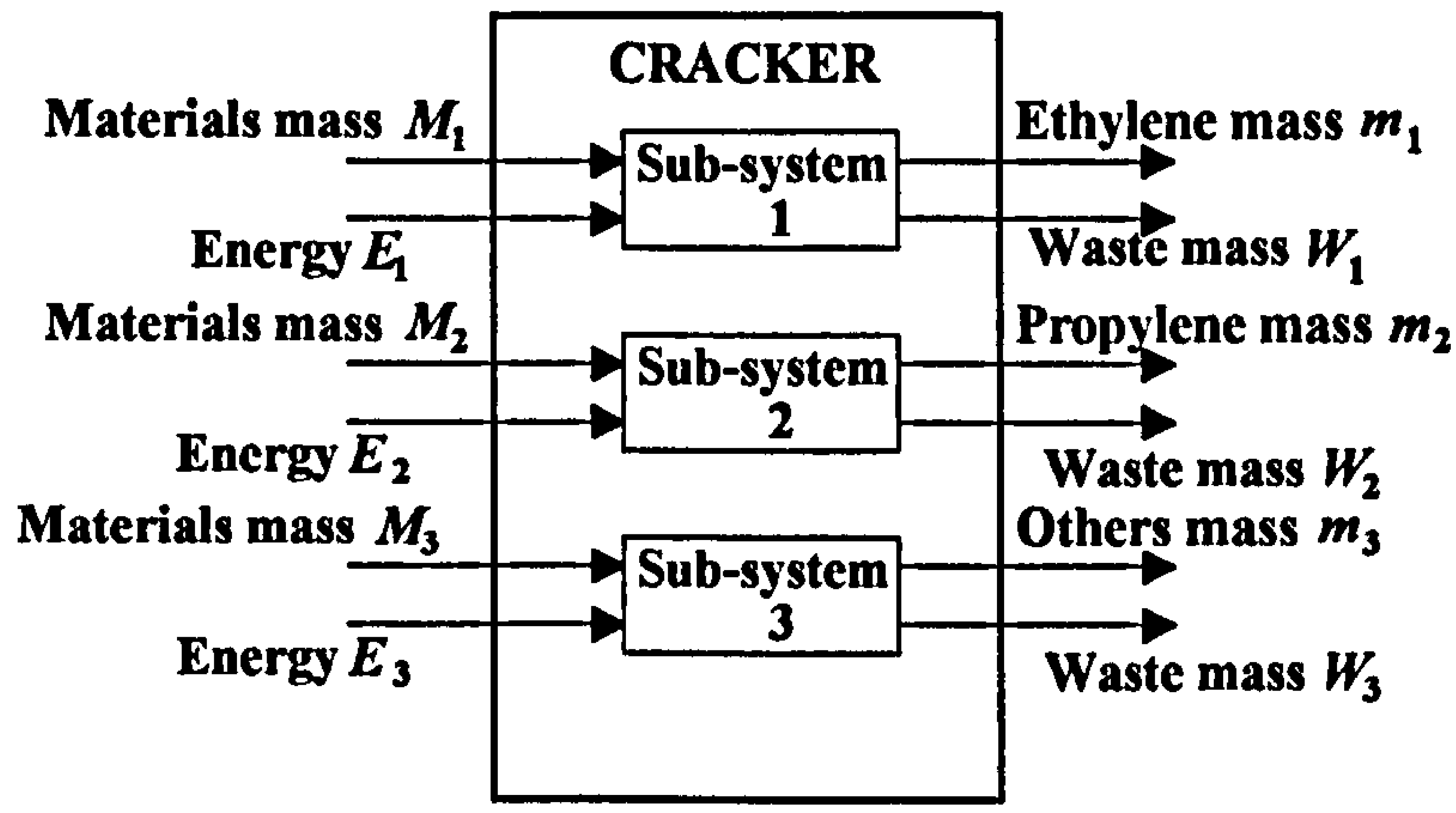


Figure 2.7 Schematic diagram of a naphtha cracker analysed into three sub-systems each producing a single product

Mass is the simplest parameter to partition the inputs and outputs for this system. Thus, since the

total mass of useful product $= M_p = m_1 + m_2 + m_3$

total mass of naphtha input $= M = M_1 + M_2 + M_3$

total mass of waste material $= W = W_1 + W_2 + W_3$

total energy input $= E = E_1 + E_2 + E_3$

the materials input attributable to the three sub-systems producing ethylene, propylene and other products will be

Ethylene sub-system: $M_1 = Mm_1/M_p$

Propylene sub-system: $M_2 = Mm_2/M_p$

'Others' sub-system: $M_3 = Mm_3/M_p$

Similarly, the allocation of energy, E_1, and waste, W_1 to ethylene production will be:

$$E_1 = Em_1/M_p$$

$$W_1 = Wm_1/M_p$$

and so on for propylene and other products.

2. The co-production of coke and manufactured gas from coal

Coke and manufactured gas are produced by the pyrolysis of coal in the absence of air. Suppose an energy input, E, is required for the pyrolysis, as shown in Figure 2.8. A coal input of mass M produces coke and manufactured gas of masses m_1 and m_2 and energy content E_1 and E_2 respectively, plus waste material of total mass W.

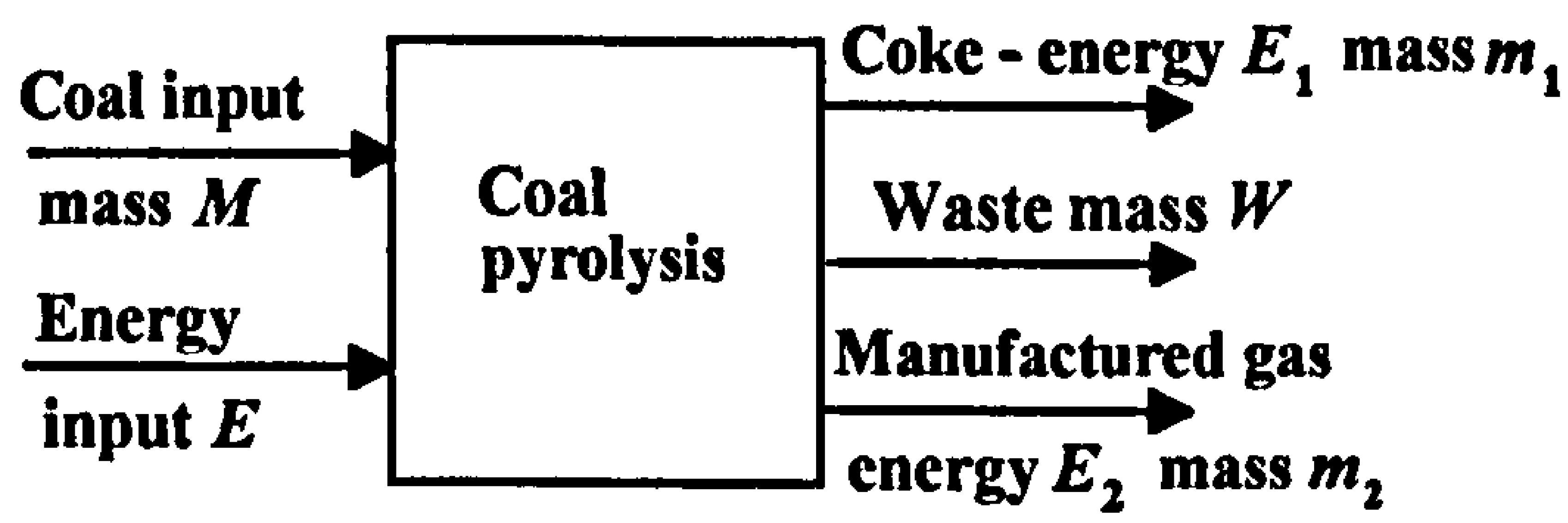


Figure 2.8 Co-production of coke and manufactured gas

In energy systems partitioning is normally carried out on an energy basis rather than a mass basis. Thus, just as thermal cracking was considered as three separate sub-systems in the previous example, for the purposes of partitioning, coal pyrolysis may be considered as two separate sub-systems producing coke and manufactured gas, as shown in Figure 2.9.

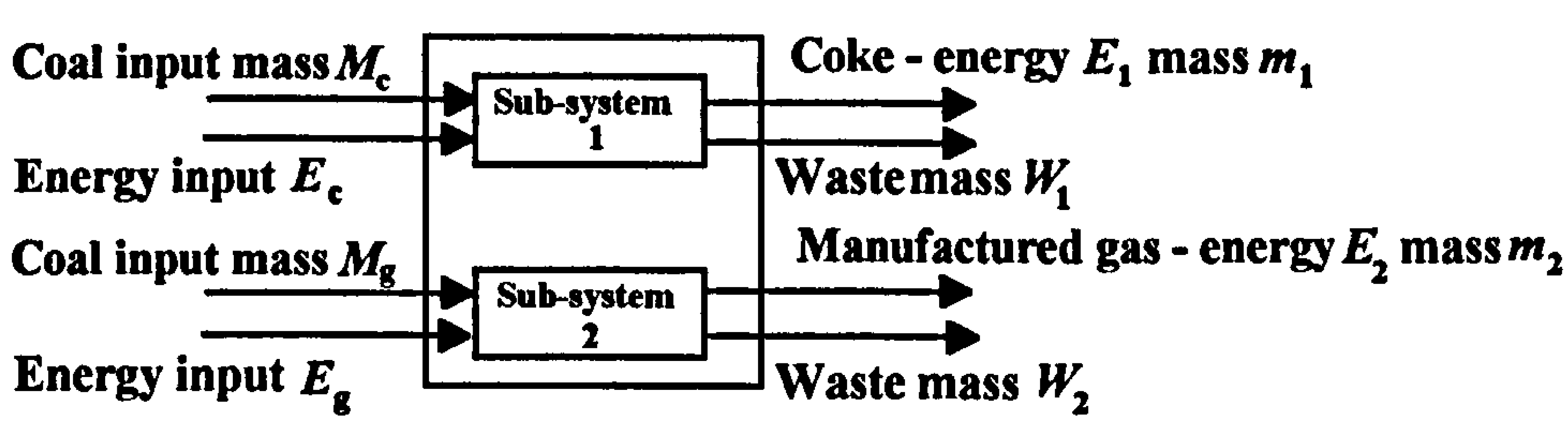


Figure 2.9 Co-production of coke and manufactured gas considered as two sub-systems each producing a single product

Thus, since the

total mass input of coal $= M = M_c + M_g$

total mass of waste material $= W = W_1 + W_2$

total energy input $= E = E_c + E_g$

total energy output $= E_1 + E_2$

the energy input attributable to the two sub-systems producing coke and manufactured gas, E_c and E_g respectively, will be,

Coke sub-system: $$E_c = \frac{E.E_1}{(E_1 + E_2)}$$

Manufactured gas sub-system: $$E_g = \frac{E.E_2}{(E_1 + E_2)}$$

Similarly, the allocation of coal input, M_c, and waste, W_1, to coke production will be,

$$M_c = \frac{M.E_1}{(E_1 + E_2)}$$

and $$W_1 = \frac{W.E_1}{(E_1 + E_2)}$$

and so on for manufactured gas.

3. The electrolysis of brine to produce chlorine, hydrogen and sodium hydroxide

Although it is tempting to apply mass partitioning to chemical processes the allocation of inputs between the various products may produce erroneous results. The difficulties of applying mass partitioning may be understood by considering the electrolysis of brine. In this process an input of electrical energy is used with mass inputs of sodium chloride and water to produce chlorine gas, hydrogen gas and aqueous sodium hydroxide, as depicted in Figure 2.10. The overall chemical equation for the electrolysis is given below.

$$2NaCl_{(aq)} + 2H_2O_{(l)} \rightarrow Cl_{2(g)} + H_{2(g)} + 2NaOH_{(aq)}$$

From the stoichiometry of the equation, and the relative atomic masses of the elements involved, it is possible to calculate the theoretical mass of the products from the reacting masses of sodium chloride and water as shown in Table 2.1. Thus, a hypothetical plant might consume 117 kg sodium chloride and 36 kg water for the production of 71 kg of chlorine, 2 kg hydrogen and 80 kg sodium hydroxide.

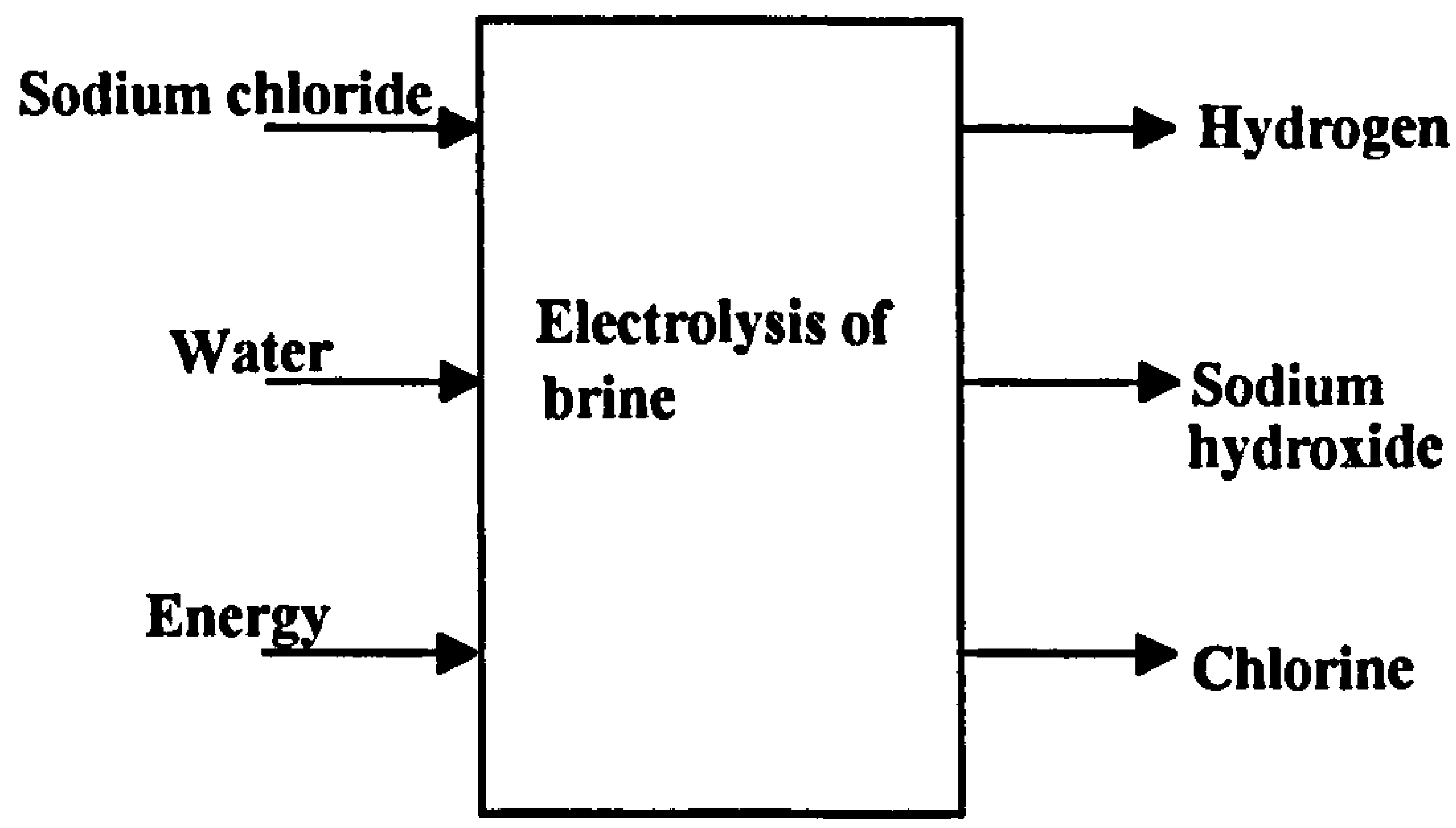


Figure 2.10 Co-products of hydrogen, sodium hydroxide and chlorine from the electrolysis of brine

Table 2.1 Material inputs and outputs for a hypothetical electrolysis plant producing chlorine, hydrogen and sodium hydroxide

	INPUTS			OUTPUTS			
	Sodium chloride	**Water**	**Total**	**Chlorine**	**Hydrogen**	**Sodium hydroxide**	**Total**
Number of moles	2	2		1	1	2	
Mass (kg). No. moles x Relative Molecular Mass[1] x 10^3	117	36	153	71	2	80	153

[1] Relative Atomic Masses: Na = 23, H =1, Cl = 35.5, O = 16

The peculiar problems associated with mass partitioning are highlighted by considering the allocation of the above sodium chloride inputs between the three products as shown in Table 2.2.

Table 2.2 Allocation of sodium chloride between products for the hypothetical electrolysis plant described in Table 2.1	
Allocation of sodium chloride input (kg)	**Product (kg)**
(117 x 71)/153 = 54.29	Chlorine Cl_2 = 71
(117 x 2)/153 = 1.53	Hydrogen H_2 = 2
(117 x 80)/153 = 61.18	Sodium hydroxide NaOH = 80
Total = 117	Total = 153

The results of this allocation are inadmissible for the following reasons.

1. The only source of chlorine is sodium chloride, yet it would appear that more chlorine is produced than is present in the original sodium chloride.
2. The allocation of sodium chloride to the production of hydrogen is inconsistent with the chemistry of the reaction, which shows that hydrogen is derived entirely from the water input, and not from sodium chloride.
3. Similarly, the chlorine content of sodium chloride is incorrectly allocated to the production of sodium hydroxide, a product which does not contain chlorine.

Clearly, the application of mass partitioning to chemical processes produces incorrect results, and another technique based on the chemistry of the reacting species is preferred. Such a technique is known as stoichiometric partitioning.

The application of stoichiometric partitioning to the electrolysis of brine may be understood by first rewriting the overall chemical equation in terms of the reacting ionic species.

$$2Na^+_{(aq)} + 2Cl^-_{(aq)} + 2H^+_{(aq)} + 2OH^-_{(aq)} \rightarrow Cl_{2(g)} + H_{2(g)} + 2Na^+_{(aq)} + 2OH^-_{(aq)}$$

From this equation it is possible to identify the reacting species with particular products, as shown in Table 2.3 and Figure 2.11.

Table 2.3 Stoichiometric partitioning for a hypothetical electrolysis plant producing chlorine, hydrogen and sodium hydroxide

	INPUTS - reacting species				OUTPUTS			
	Sodium chloride		Water		Chlorine gas	Hydrogen gas	Sodium hydroxide	
	Sodium ions Na^+	Chloride ions Cl^-	Hydrogen ions H^+	Hydroxide ions OH^-	Cl_2	H_2	Na^+ ions	OH^- ions
Number of moles	2	2	2	2	1	1	2	2
Mass (kg). No. moles x Relative Formula Mass[1] x 10^3	46	71	2	34	71	2	46	34

[1] Relative Atomic Masses: Na = 23, H =1, Cl = 35.5, O = 16

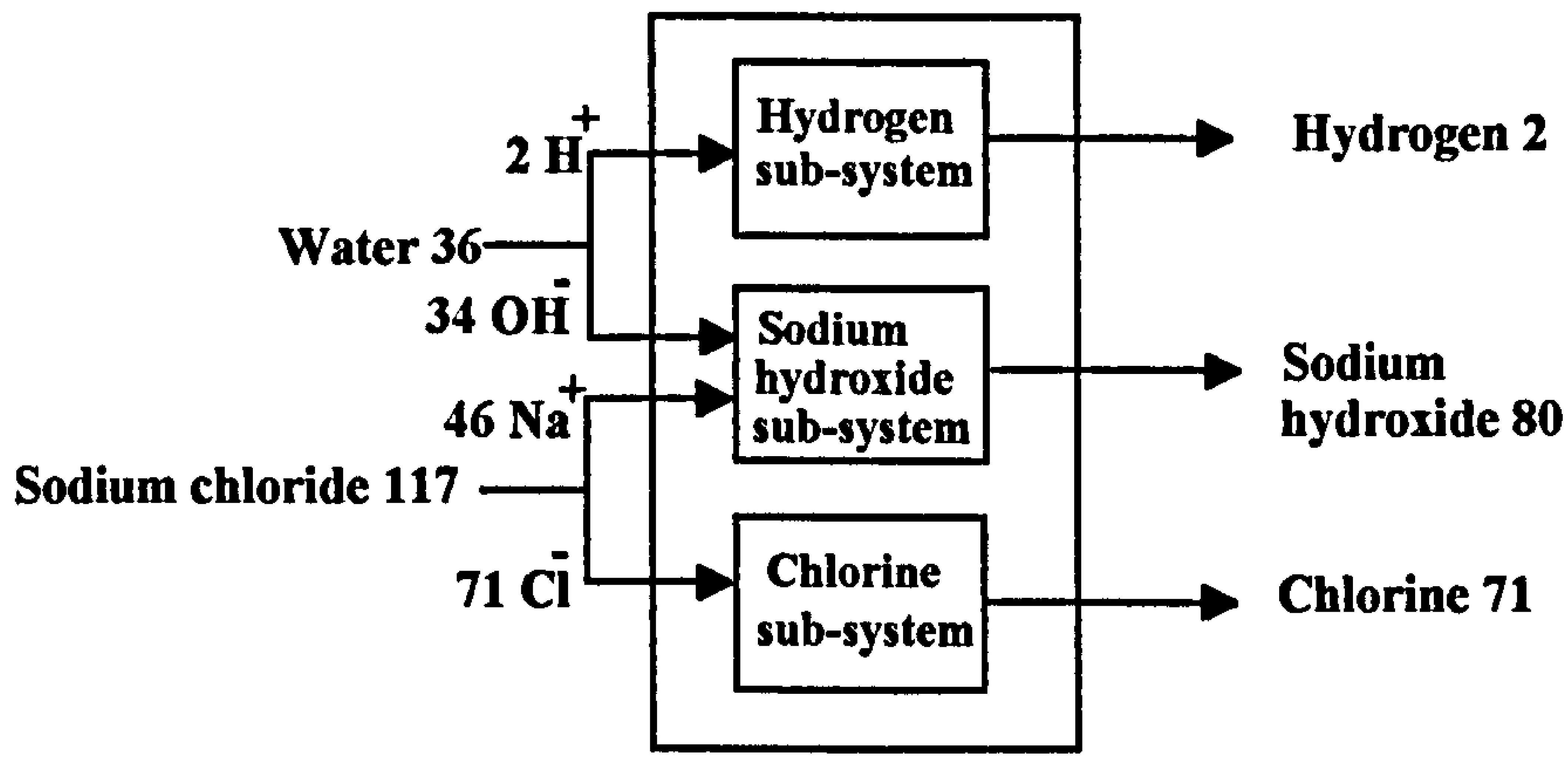


Figure 2.11 Schematic diagram of brine electrolysis showing stoichiometric allocation of inputs between three sub-systems, each producing a single product. Mass flows in kg

Thus:

71 kg $Cl^-_{(aq)}$ ions produce 71 kg $Cl_{2\,(g)}$

2 kg $H^+_{(aq)}$ ions produce 2 kg $H_{2\,(g)}$

46 kg $Na^+_{(aq)}$ ions and 34 kg $OH^-_{(aq)}$ ions produce 80 kg $NaOH_{(aq)}$

Notwithstanding the use of stoichiometric partitioning for inputs of sodium chloride, not all inputs and outputs may be allocated in this way; for example, energy inputs. In such cases it is appropriate to partition on a mass basis.

2.3 Capital items

The construction of the plant and equipment required for industrial systems to function will consume considerable quantities of fuel and raw materials, and produce commensurate quantities of waste material. The data associated with these operations should strictly be included in the life-cycle inventory of the product, but their effect is insignificant when compared with the inventory flows of the product throughput during the lifetime of the plant. For example, consider a hammer mill weighing 29 tonnes used in a clay preparation plant. If it is assumed that the machine is constructed entirely from steel with a gross production energy of 32 MJ/kg, then the total capital energy is 9.3×10^5 MJ. If the hammer mill has a life expectancy of twenty years and processes clay at the rate of 1,500 tonnes per day, and if the clay processing energy is 1.0 MJ/kg, then the energy associated with the clay throughput is 1.5×10^6 MJ per day or 7.5×10^9 MJ over the lifetime of the machine. From these figures it can be shown that the capital energy makes a contribution of 0.01 % to the processing energy during the lifetime of the machine, which is much less than the accuracy of industrial data, and is therefore ignored in this work.

2.4 Human resources

Humans inputs make an important contribution to manufacturing processes and should strictly be considered part of the life-cycle inventory of manufactured goods. These contributions arise from two sources:

- food consumption
- transport to work.

An average human consumes about 40 kcal (0.1672 MJ) of food per kg live body weight per day.[54] For an average human of mass 80 kg the food intake has an energy of 13.4 MJ, 80 % of which is used to generate body heat and to maintain other body functions. Thus, only 20 %, or 2.7 MJ, is available for external work. It is useful to compare this energy with the energy associated with manufacturing operations. For example, consider the clay preparation plant discussed earlier. Suppose ten humans are employed in all the operations involved from the extraction of clay in the ground through to the operation of the hammer mill. The total energy available for human work is (10 x 2.7) MJ or 27 MJ per day, which adds only 0.002 % to the daily processing energy of 1.5×10^6 MJ.

The contribution arising from transport to work is higher and may be estimated as follows. Suppose a worker travels alone to work by car. If the petrol consumption of the car is 10.6 km per litre (approx. 30 m.p.g), and the gross energy of petrol is 36 MJ per litre, the energy of a return journey of 48 km will be 163 MJ. Thus, if it is assumed that the workforce of ten humans employed in the chain of operations starting with clay in the ground through to the hammer mill, all make similar journeys to work, an additional daily energy contribution of 1,630 MJ, or 0.1 %, should be added to the daily processing energy of 1.5×10^6 MJ.

The small increases in the daily processing energy attributed to food intake and transport to work are well below the accuracy of industrial data and consequently both these contributions will be ignored in this work.

2.5 Sources of information

The three main sources of data used in life-cycle assessment studies are:

1. published statistics
2. published literature
3. commercial sources

The first source of information is published statistics, which are normally available from government sources, trade associations or research councils. The use of such information suffers from a number of disadvantages. First, and most seriously, the data are presented in an aggregated form, from which it is usually impossible to separate and identify a particular source. Second, since the method by which the raw data is collected and the number of contributors involved are often unknown, there is an element of doubt concerning the accuracy of such figures. Nonetheless, published statistics are sometimes the best or only source of information and have been used as required in this work; for example, when deriving fuel production and delivery efficiencies.

The second source of information is open literature publications, which, unlike published stastistics, are relatively free from aggregation problems and uncertainties regarding accuracy. Nonetheless, a potential problem may arise if public statistics have been used in the derivation of reported values. Although published work often provides useful values for unknown production parameters, especially when such information is witheld for reasons of confidentiality, it is sometimes dated by advances in technology and may refer to obsolete processes. Moreover, the time delay between data collection and publication creates a further limitation. Despite these disadvantages, open literature values have been used when necessary in this research.

Commercial organisations are the third source of information, and have been used extensively throughout this research, especially for gathering primary data for the production of building materials. Personal contact and the supply of up-to-date data, in the form requested, are the main advantages of this source of information. Data sources have been acknowledged throughout this report except when confidentiality is an issue. It is important to note that some of the data in this work have been obtained from single sources and values should not be considered as representative.

2.6 Data collection

The gathering of reliable comprehensive data from commercial sources is a particularly difficult exercise. Some of the major obstacles in this area are:

- confidentiality of data
- incomplete or absent data
- specificity of data
- accuracy of data
- variation in data format
- type of plant

A further insight into each of these problems is provided below.

2.6.1 Confidentiality of data

The issue of confidentiality does not arise when life-cycle inventories are completed for internal use within an organisation. However, when undertaken for external use, as in the case of this research, some or all of the data may be withheld for reasons of commercial confidence, thus making a meaningful analysis difficult or impossible. Some methods of dealing with incomplete data are examined below.

2.6.2 Incomplete or absent data

Data gaps may arise out of issues of confidentiality as described above, or, as in the case of air and water emissions, because producers are chiefly concerned with conforming to environmental pollution regulations and only monitor selected discharges. In the latter case, if partial data sets are available from a number of different producers then an average but more complete data set can be estimated. Alternatively, in the case of regulated discharges, if it is assumed that a producer is satisfying environmental regulations then an upper limit may be placed on any known emission. Although it is always preferable to use actual data, in those instances where a primary data source remains unavailable, as with a monopoly supplier witholding for confidential reasons, then secondary source data such as theoretical or open literature values may be substituted. This solution is more acceptable when the missing input is far removed from the major production sequence and makes a relatively small contribution to the final result. Nonetheless, it is important in such cases to perform a sensitivity analysis to assess how the degree of variation in the secondary source data affects the overall conclusions.

2.6.3 Specificity of data

Data from primary sources may differ considerably for the manufacture of the same product. Such variations may be site-specific or process-specific and depend on factors such as the period of time over which measurements are made, the age and efficiency of the manufacturing plant, the technology used, and in some instances on the type of material input. The clay brick industry provides examples of both types of variation. Since the chemical composition of clay may vary from one brickwork to another, both fuel consumption and air emissions may be affected, thereby giving rise to site-specific variation.

For example, for brickworks using the same type of kiln, clay with a high carbon content will consume less fuel during firing,[55] whilst emissions of sulphur dioxide would be higher for clays with a relatively high sulphur content.[56, 57] On the other hand, process-specific variation may accompany a change in technology. For instance, a reduction in fuel consumption would be expected for any given clay if an intermittent kiln was replaced by the more efficient continuous kiln.[55]

Where a sufficient number of independent data sources is available an industry average may be calculated. This is especially useful for external inventories when confidentiality may be an issue. Because the choice of data can affect the final outcome of life-cycle analysis it is important when constructing a life-cycle inventory to provide full details of the data source, and to indicate whether case-specific or average data is used. Where average data are preferred, the range of values should be quoted and a sensitivity analysis performed to assess how the variation in input data affects the final result.

2.6.4 Accuracy and reporting of data

It has been reported that the accuracy with which manufacturers record energy use and material flows is at best correct to within 5 %, and over periods of time less than twelve months a figure of 10 % is thought to more appropriate.[53] Some possible explanations for such discrepancies are material losses, weighing errors, stock changes and materials in transit. A further difficulty, superimposed on inaccurate record keeping, may occur in plants subject to short term fluctuations in the production rate but with a fixed rate of fuel consumption, and arises out of the usual practice in life-cycle analysis of normalising inputs and outputs in terms of unit product output; for example, energy consumption in terms of

MJ/kg of product. For instance, a plant producing timber products may need to maintain a constant level of humidity throughout the factory irrespective of the production rate. This can only be achieved by consuming fuel at a constant rate. Thus, short term variations in the rate of production will produce corresponding short term variations in fuel consumption when expressed in terms of MJ/kg of product. However, by taking readings over a long period of time such as twelve months, fluctuations in the production rate are smoothed out to give a more accurate and reliable value. It is always better, therefore, to collect data measured over as long a period as possible, preferably twelve months as a minimum. Although the accuracy of data is at best correct to within 5 %, in order to to avoid rounding errors all intermediate calculations in this work are quoted to four decimal places.

2.6.5 Variation in data format

Manufacturers record data in a number of different formats. In most cases there is little difficulty in expressing these data on an appropriate unit output basis. The exceptions are air and water emissions which are normally required by regulatory authorities to be expressed in concentration terms such as mg/m^3 or mg/l. Unless the emission flow rate is known it is difficult to express these concentrations in terms of unit product output. In the case of air emissions, however, an approximate solution to this problem is possible for processes using a gaseous fuel, by assuming that the emission flow rate is the same as the known rate of gas consumption, plus an allowance of about 5 % for air intake.

2.6.6 Type of plant

The degree of difficulty in collecting data will be related to the complexity of the manufacturing process being investigated. Petrochemical plants, for example, are extremely complex installations simultaneously manufacturing many differents products on the one site. Moreover, in the petrochemical industry, it is not uncommon for a network of different plants on adjacent sites to trade surplus energy and materials with each other in the interests of efficiency, and some may share common facilities such as steam raising or effluent treatment plants to add to the complexity. In these situations it is very difficult to trace accurately material flows and partition energy usage or waste material production between the various products. By comparison, many small producers, such as a clay brickworks, have a relatively independent existence and operate uncomplicated plants with few co-products. Data collection for this type of plant is a relatively simple exercise.

2.7 Calculations

The performance characteristics of industrial systems are calculated using the procedure described in Section 2.7.1 together with data for each of the following inputs and outputs.

1. Energy
2. Fuels
3. Feedstocks
4. Raw materials consumption
5. Emissions to air
6. Emissions to water
7. Solid waste production

Most data rely directly on physical measurements. However, some outputs, such as emissions of carbon dioxide, are seldom measured directly, and are calculated instead. The method of calculating carbon dioxide emissions is described in Section 2.7.2.

2.7.1 Procedure for calculating performance characteristics

1. Starting from raw materials in the ground, a detailed flow chart for all the operations up to the final product is drawn up. In constructing the flow chart it is worth noting that most processing sequences may be conveniently represented as three main groups, processing, packaging and delivery, as shown in Figure 2.12.

Figure 2.12 Simplified flow chart for industrial manufacturing systems

2. The ouput from the final operation is set to unity
3. Using material conversion efficiencies and the mass inputs to each unit operation a mass balance linking the unit operations in the process sequence is calculated.
4. Normalised inputs and outputs to each unit operation are calculated as described in Section 2.2.3 and 2.2.4
5. By multiplying the normalised data by the mass output the contribution made by each unit operation to the overall system is calculated.
6. Finally, the separate contributions from each unit operation are added together to obtain gross inputs and outputs for the whole system.

Instead of calculating stages 5 and 6 by hand, the normalised inputs and outputs for each unit operation, as calculated in stage 4, may be used as input data in a computer model, which is then used to complete the calculations in stages 5 and 6. The calculation procedure outlined above may be illustrated with the following simple example relating to gross energy usage. The calculation of other gross inputs and outputs is carried out in a similar manner.

Consider a three stage linear sequence of unit operations, A, B and C, producing 1 kg of product as shown in Figure 2.13. The material conversion efficiencies and normalised energy input for operations A, B, and C are as shown.

By completing a mass balance calculation using the material conversion efficiencies, it can be shown that a mass input of 1.4619 kg to unit operation A is required to produce a downstream ouput of 1 kg of product from unit operation C. The gross energy, *E*, for the system may be derived from the normalised energy input to each unit operation as follows.

$$E = [(2 \times 1.3158) + (3 \times 1.0526) + (4 \times 1)]$$
$$= 9.79 \text{ MJ/kg}$$

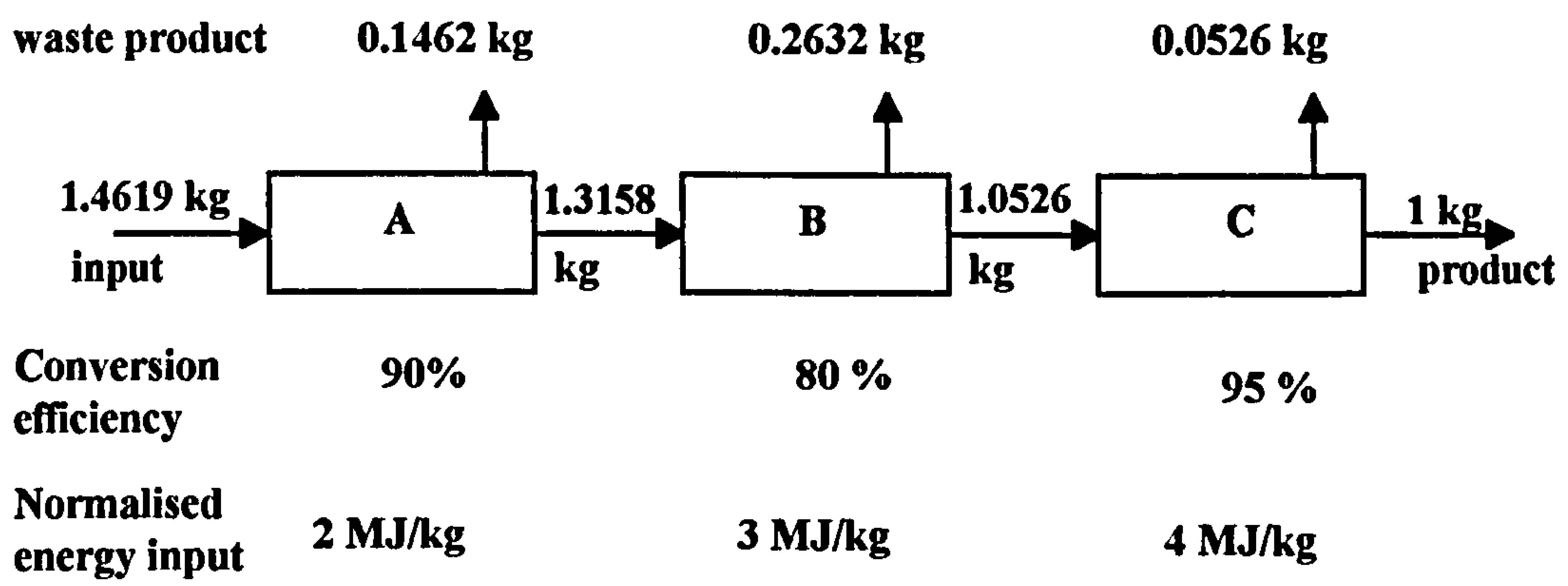


Figure 2.13 An example of a simple linear sequence showing a mass balance for unit product output

2.7.2 Carbon dioxide calculations

Carbon dioxide is formed when carbon or carbon compounds are burned in a plentiful supply of air or oxygen, or from chemical reactions such as the thermochemical decomposition of carbonates such as calcium carbonate (limestone). Emission levels may be calculated from the stoichiometry of the chemical reaction describing its formation. For example, assuming complete combustion, the carbon content of fossil fuels, such as coal, will burn in air producing carbon dioxide according to the following equation.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

Formula masses 12.01 32.00 44.01

Formula masses have been calculated using the relative atomic masses of carbon and oxygen as 12.01 and 16.00 respectively.

Using formula masses it can be deduced that:

12.01 kg carbon produces 44.01 kg carbon dioxide

or, *1 kg carbon produces 3.664 kg carbon dioxide.*

This relationship is used to calculate carbon dioxide emissions arising from the complete combustion of a hydrocarbon fuel such as coal. For example:

Let the carbon content of coal = 80 %

Then the mass of carbon present in 1 kg of coal = 0.80 kg

Mass of carbon dioxide produced on complete combustion of 1 kg coal = 0.80 x 3.664

= 2.93 kg

Maximum carbon dioxide emissions are only produced when a fuel burns completely. However, in many combustion reactions it is unlikely that sufficient oxygen is present for the conversion of all the carbon to carbon dioxide. In these circumstances some carbon monoxide, and possibly some soot (pure carbon) is formed. In such cases the theoretical carbon dioxide emissions are too high and must be reduced by subtracting the carbon dioxide equivalent of carbon monoxide and carbon respectively.

The carbon dioxide equivalent of carbon has already been derived as:

1 kg carbon is equivalent to 3.664 kg carbon dioxide (see above).

The carbon dioxide equivalent of carbon monoxide is calculated from the equation describing its conversion to carbon dioxide as shown below.

$$CO_{(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow CO_{2(g)}$$

Formula masses 28.01 16.00 44.01

Again, using formula masses:

28.01 kg carbon monoxide produces 44.01 kg carbon dioxide

or, *1 kg carbon monoxide is equivalent to 1.571 kg carbon dioxide*

2.8 Presentation of results

The results of the life-cycle inventory calculations will form a data set for each operation or system under each of the seven main performance characteristics listed in Section 2.7. For each of these characteristics, data may be expressed as *unit data* for isolated operations, or as *gross data.* The term *gross data* refers to the cumulative total of all inputs and outputs beginning with the extraction of raw materials from the earth through to the final production sequence. Since life-cycle inventory calculations are ultimately concerned with gross data, the results of this research will be presented in this form, and tabulated as shown in the exemplar set of results for polyethylene film production in Table 2.4 on p. 39. Unless otherwise stated, all data in this work are recorded in SI units, for example, tonne, kg, mg for mass and MJ for energy.

It is useful to consider the format of Table 2.4. Firstly, it is designed to present gross energy data in terms of the fuel producing industries under the heading *Energy.* A second objective is to provide a complete set of input-output data under the headings *Primary fuels, Primary feedstocks, Raw materials, Air emissions, Water emissions,* and *Solid waste.* The input-output data set represents the total burdens on the environment for the system being considered. A further explanation and interpretation of the contents of the table are given below.

2.8.1 Gross energy data

The gross energy data are presented both in terms of the fuel producing industries under the heading *Energy*, and as the sum of the fuel and feedstock inputs under the headings *Primary fuels* and *Primary feedstocks*. Although the two methods of presentation show different details, the total energy consumption is the same in both cases. Any differences betweeen the two totals are small and attributed to iteration or rounding errors. The significance of the two representations is developed in the following paragraphs.

When considered in terms of the fuel producing industries the gross energy data have been grouped together as *electricity, oil fuels, and other fuels*. The *electricity industry* is given particular attention because of its relatively low production efficiency, the lowest of all the fuel supply industries. The *oil industry* supplies a variety of different fuels, each derived from crude oil, and each with the same production efficiency. For these reasons the oil industry is given special consideration. For simplicity the remaining fuel producing industries, such as coal, coke, natural gas, and biological fuels are considered together under the heading *Other fuels*, although further subdivisions for each fuel are possible. Energy data for each fuel producing industry are broken down further as *production and delivery energy, delivered energy and feedstock energy.*

- The *production and delivery energy*, or indirect energy, is the energy used by the fuel producing industries in primary fuel extraction from the ground, subsequent processing and delivery to the consumer. It is dependent on the country in which the fuel is produced and delivered. For example, in 1991, U.K. grid electricity was produced and supplied with an efficiency of approximately 30 %, compared to 48 % in Sweden. This implies that for every unit of electricity delivered, another 2.3 units of energy were consumed by the electricity producing industry in the U.K., compared to 1.08 units in Sweden. Variations in the efficiencies of electricity production and supply, from one country to another, are accounted for by the mix of primary fuels and the generating techniques used.

- The *delivered energy*, or direct energy, is the energy delivered to and used by the consumer.
- The *feedstock energy* is the energy content of fuel containing materials that are used as a material input, and not as a fuel. For example, wood in the paper industry. No entry is possible for electricity since by its very nature it cannot be a feedstock. Feedstock energy is to be examined in more detail in Chapter 3.

In contrast to the *production and delivery energy*, both *delivered energy* and *feedstock energy* are independent of country, but are governed by the demand for energy and the technology used by the consumer. For example, in Table 2.4 the sum of the delivered energies attributed to *electricity*, *oil*, and *other* fuels (28.13 MJ), and the total *oil* and *other* fuel feedstocks (48.70 MJ), are dependent on the process technology. For the same technology these values will remain unchanged from one country to another. The opposite is true, however, for the total *production* and *delivered energy* (22.96 MJ), which is dependent on the fuel production industries of each country. Thus, by ignoring the country dependent production and delivery energies, it is possible to compare technologies or plants using the same technology, between different countries. Comparisons of this nature highlight an important advantage of this mode of presentation.

The second format used for presenting gross energy data is as inputs of *Primary fuels and Primary feedstocks*. Here the energy requirements are considered in terms of primary fuels and feedstocks that are extracted from the ground. The fuel and feedstock entries under coal, oil, gas, etc. do not refer to the respective fuel producing industries, but to the quantities of coal, oil and gas, etc. removed from the ground. This format has the advantage of identifying the primary energy resources required to sustain the system. Moreover, by separating the non-renewable fossil fuels coal, oil and gas, it allows the dependence on fossil fuels to be examined. This type of information is of particular interest to environmentalists, for example, when considering the depletion of fossil fuel reserves. Finally, it enables the contribution from nuclear fuels and renewable fuels such as hydro-electricity, wood and biomass to be considered. Thus, for example, it is evident from Table 2.4 that the production of 1 kg of polyethylene film is heavily dependent on fossil fuels (45.89 MJ) and feedstocks (48.71 MJ). In contrast, the contribution from nuclear fuels (4.95 MJ) and hydro-electricity (0.24 MJ) is small by comparison. As with the first format, primary fuel data are separated from feedstock data, which, it should be noted, are the same in both formats.

Table 2.4 Gross inputs and outputs associated with the production of 1 kg polyethylene film Totals may not agree because of rounding errors		
Energy	**Units**	
Electricity - production & delivery	MJ	14.08
Electricity - delivered	MJ	5.96
Oil fuels - production & delivery	MJ	4.49
Oil fuels - delivered	MJ	7.75
Oil fuels - feedstock	MJ	24.05
Other fuels - production & delivery	MJ	4.39
Other fuels - delivered	MJ	14.42
Other fuels - feedstock	MJ	24.65
Total energy	MJ	99.79
Primary fuels		
Coal	MJ	12.66
Oil	MJ	12.51
Gas	MJ	20.72
Hydro	MJ	0.24
Nuclear	MJ	4.95
Lignite	MJ	0.00
Total fuels	MJ	51.07
Primary feedstocks		
Coal	MJ	0.02
Oil	MJ	24.04
Gas	MJ	24.64
Total feedstock	MJ	48.71
Total fuels & feedstock	MJ	99.78
Raw materials		
Bauxite	mg	312
Brine	mg	3
Clay	mg	20
Fe-Mn	mg	5
Iron ore	mg	1,329
Lead	mg	1
Limestone	mg	580
Met coal	mg	463
Sand	mg	5
Water	mg	2,555,400
NaCl	mg	7,140
Air	mg	108
Sulphur	mg	7
Air emissions		
Dust	mg	5,563
CO	mg	1,456
CO2	mg	2,972,300
SOx	mg	16,295
NOx	mg	14,195
HCl	mg	208
HF	mg	8
HC	mg	21,958
CHO	mg	5
Organics	mg	5
Metals	mg	2
CH4	mg	2,152
Hydrogen	mg	1
Water emissions		
COD	mg	1,022
BOD	mg	154
Acid	mg	90
NO3-	mg	5
Metal ions	mg	312
NH4+	mg	5
Cl-	mg	122
Dissolved organics	mg	20
Dissolved solids	mg	408
Suspended solids	mg	702
Hydrocarbons	mg	104
Detergent/oil	mg	102
Other N	mg	10
$SO_4^{=}$	mg	10
Phenol	mg	2
Phosphate/P2O5	mg	5
Solid waste		
Mineral waste	mg	75,585
Slags\ash	mg	23,091
Industrial waste	mg	3,319
Regulated chemicals	mg	71
Unregulated chemicals	mg	2,040

2.8.2 Gross raw materials

The gross raw materials data refer to the cumulative totals of the primary raw materials extracted from the ground, and are a measure of the depletion of the Earth's resources.

2.8.3 Gross emission data

Similarly, the gross emission data refer to the cumulative totals of waste material arising from all operations in the production sequence starting with raw materials in the ground through to the point of use by the consumer, and include air emissions, water emissions, and solid waste production. Such information is of interest to environmentalists concerned with potential pollution problems.

Although it is possible to consider emissions as originating from one or more of the following general sources; *fuel production, fuel burning, transport, process operations*, and *biomass*, the results of this research present the emission data in an aggregated form. Nonetheless, it is instructive to examine the origins of some of these emissions in more detail, as shown in Table 2.5 where a selection of emissions is identified by type, source and specimen operation.

2.8.4 Conclusion

Finally, it must be emphasised that despite the sole reference in the input-output table headings to the final production sequence, the data refer to the cumulative totals associated with the final product, and include all the production sequences starting with raw materials in the ground through to the point of use of the final product by the consumer. It is incorrect to interpret the data as referring exclusively to the final production sequence.

Table 2.5 Examples of emission data identified by type, source and specimen operation		
Emission type	**Source**	**Specimen operation**
Air emissions		
CH_4	Fuel production	Coal mining, natural gas extraction & delivery
CO_2, SO_2, NO_x, HC, dust	Fuel production	Combustion of coal used in electricity generation
Ditto	Fuel burning	Combustion of coal by consumer
CO_2, NO_x	Fuel burning	Combustion of natural gas by consumer
CO_2, NO_x, HC, dust, lead	Transport	Combustion of oil fuels used in transport operations
CO_2	Biomass	Combustion of wood
Ditto	Process	Thermochemical decomposition of limestone during cement manufacture
HCl	Process	Flat glass manufacture
N_2O	Process	Production of nitric acid and adipic acid
H_2	Process	Production of aerated concrete blocks Electrolysis of brine
SO_2, HC	Process	Oil refining & cracking operations
HF, SO_2, NO_x	Process	Firing of clay during clay brick manufacture
Water emissions		
Suspended solids	Fuel production Process	Coal washing Cement manufacture (wet process)
COD, COD and phenol	Fuel production	Oil refining
Dissolved solids, salt	Process	Solvay process (sodium carbonate production)
Acid & metals	Process	Iron blast furnace
Fe, Sn, Cr	Process	Galvanising of steel
Na^+ and Cl^- ions	Process	PVC manufacture
Solid waste		
Mineral waste	Fuel production Process	Earth/rock removal during coal mining Ditto - other mining operations
Slags/ash	Fuel production Process	Coal mining operations Combustion of coal in furnaces
Regulated waste	Process	Toxic or corrosive waste from chemical processes
Unregulated waste	Process	Non-toxic waste from chemical processes
Industrial waste	Process	Any other solid waste

Chapter 3

FUELS

3.1 Introduction

Fuels are an important element of life-cycle assessment studies and are of special interest both as an energy resource material and as a source of air emissions on combustion. They may be described as materials from which energy may be derived, and fall into two distinct groups, primary and secondary. Primary fuels include nuclear fuels, fossil fuels such as coal, natural gas, and oil, and renewable fuels such as wood. Secondary fuels such as electricity, coke, and manufactured gas are derived from primary fuels.

With the exception of nuclear fuels and electricity, most fuels contain carbon and hydrogen and owe their importance to the exothermic chemical reactions taking place with oxygen on burning.

$$C + O_2 \rightarrow CO_2$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

The energy released on combustion of unit quantity of fuel is called the calorific value. For fuels containing hydrogen, two types of calorific value are often quoted; the gross calorific value and the net calorific value. The gross calorific value is defined as the heat evolved when all the products of combustion are cooled to standard conditions of temperature and pressure (i.e. a temperature of 25° C and 1 atmosphere pressure), and will include the latent heat of vaporisation of water and the heat associated with the temperature change on cooling the water to 25°C. The latter is sometimes known as the sensible heat of water. The net calorific value is the heat evolved when the water remains in the gaseous state. The net value does not include the latent heat of vaporisation or sensible heat, and is therefore less than the gross value. For example, the gross calorific value of methane is 53.42 MJ/kg compared to the net value of 48.16 MJ/kg,[58] a difference of approximately 10 %. Gross calorific values are used in this work since they represent the maximum energy obtainable from a given fuel.

3.2 Feedstock energy

The inputs of raw materials to industrial operations are frequently referred to as *feedstocks*. Accounting for inorganic feedstocks is a relatively straightforward procedure since the total input will eventually appear as waste material or usable product. However, some organic feedstocks can be used as either a fuel input or as a material input, for example, oil products in the petrochemical industry or wood in the paper industry. When these materials are used as a fuel the energy content, or *fuel energy*, is destroyed for ever with the release of thermal energy and the evolution of gaseous emissions. Such use represents a permanent depletion of energy resources. In contrast, if used as a material input the energy content remains intact and 'locked up' in the final product. This 'locked up' energy is described as *feedstock energy or rolled-up feedstock energy*. Moreover, since the material is not burned no air emissions are produced.

Although feedstock energy may be regarded as a witheld or stored resource, part of it may be recovered along with associated air emissions, by burning at the end of the useful life of the product. Nonetheless, the fuel content of the product is not necessarily equal to the input feedstock energy and may differ for two reasons. First, the chemical structure of the materials may alter during the process, and since the energy content is dependent on chemical structure the available energy will also change. The second reason for the difference arises from material losses during processing.

Thus, *feedstock energy is calculated as the energy content (gross calorific value) of the input material, not the output.*

In some industries, such as the petrochemical or timber-producing industries, waste materials are often used as fuels. On these occasions feedstock energy is converted into fuel energy altering the balance between fuel and feedstock, and suitable adjustments must be made to the life-cycle inventory.

In recognition of their different characteristics, fuel energy and feedstock energy must be accounted for separately when analysing the total energy input to a process.

3.3 Fuel production and delivery efficiency

The processing of a primary fuel into a usable form, or its conversion into a secondary fuel, requires an input of energy. A further energy input is required for its subsequent delivery to the point of use by the consumer. If E_c and E_p represent the energy content of the fuel, and the processing and delivery energy respectively, the total energy extracted from the ground will be $(E_c + E_p)$. The quantity, E_c, represents the maximum energy available to the consumer and is termed the **direct** or **delivered** energy content. Using the above notation, the fuel production and delivery efficiency, α, may be expressed as:

$$\alpha = \frac{E_c}{E_c + E_p}$$

Conversion losses ensure that the production and delivery efficiency of a secondary fuel will always be less than that of the primary fuel from which it was derived. The overall production route for any fuel may be regarded as a linear sequence of operations, each with its own energy conversion efficiency, α_n. For example, electricity production may be regarded as a four stage sequence as depicted in Figure 3.1.

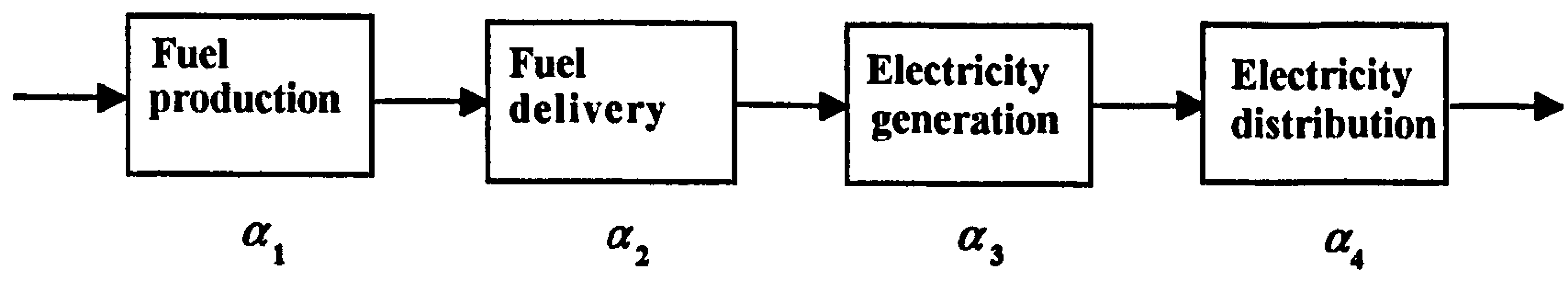


Figure 3.1 Process sequence for the production and delivery of electricity

Using the conversion efficiencies for each operation, the overall efficiency, η, will be given by

$$\eta = \alpha_1 . \alpha_2 . \alpha_3 . \alpha_4$$

The production and delivery efficiency for each fuel will vary depending on the energy required for processing and delivery. For fossil fuels, little variation is noted from one country to another, and most figures lie in the range 80 % to 95 % depending on the fuel. However, a large variation is found between countries for electricity generation. For those countries with hydro-electric power, efficiencies as high as 80 % are recorded, whereas the efficiency of thermally generated electricity is seldom better than about 35 %.

3.4 Fuel producing industries

The energy required to support manufacturing processes is supplied by the fuel producing industries. Therefore, as a necessary pre-requisite to further analysis and before the gross inputs and outputs to manufacturing processes can be calculated, it is proposed to consider the fuel producing industries as belonging to extended industrial systems, and, by using recent data, to complete a life-cycle analysis for the production, processing, delivery and use of each of the following fuels; natural gas, oil fuels, coal, coke, manufactured gas and electricity. The analyses relate to 1991, a recent year for which a full set of data is available. The life-cycle inventory calculations will generate the gross inputs and outputs associated with 1 MJ of each fuel.

Taking natural gas as an example, the production and supply of all primary fuels and secondary fuels such as coke and manufactured gas, from natural resources in the ground to the final point of use by the consumer, can be regarded as a simple linear sequence of the four main operations represented schematically in Figure 3.2. Since the process sequences and the preparation of the life-cycle inventories are similar for each of these fuels, only one fuel, natural gas, will be discussed in detail. The process sequence for electricity is slightly different and is considered separately.

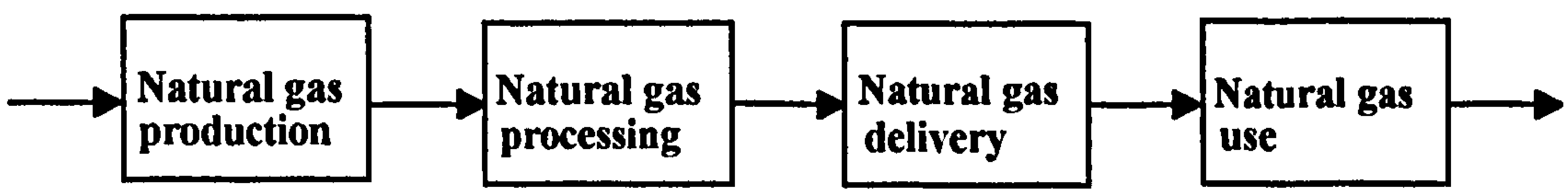


Figure 3.2 Process sequence for the production and delivery of natural gas

3.4.1 U.K Natural gas production and supply

U.K. natural gas is extracted mostly from offshore gas or oil wells situated on the U.K. Continental Shelf. The extraction involves drilling and pumping operations together with associated gas losses or own use, summarised by Makhijani and Lichtenberg [5] as including gas used for pipeline power, pipeline losses and gases vented and wasted. Table 3.1 provides details of the UK Natural Gas Production & Supply for 1991, plus unit inputs and outputs for the operations *Natural gas processing* and *Natural gas delivery*.

Table 3.1 UK Natural gas production & supply: unit inputs and outputs						
Source: Tables 20,24,40,41,48 - Digest of UK Energy Statistics1992			Unit inputs and outputs/MJ gas			
			Nat. gas processing		Nat. gas delivery	
Production & supply	**TJ**	**TJ**	**Fuel use MJ**	**Air emissions mg**	**Fuel use or loss MJ**	**Air emissions mg**
Indigenous	2,143,390					
Imports	264,719					
Gross availability before disposal		2,408,109				
Disposal						
Own use- drilling & pumping*						
- Indigenous	-46,870					
- Imported (estimate)	-5,665					
		-52,535 **A**	A/B =	see		
		2,355,574 **B**	0.02230	Table 3.2		
To others	-116					
Crude oil extraction	-86,757					
		-86,873				
Net availability before delivery		2,268,701				
Delivery						
Offshore distribution losses-CH_4 (estimated)	-96,157					
Onshore distribution losses -CH_4	-72,856					$\frac{C \times 10^6}{54.1144^{**} \times E}$
		-169,013 **C**			C/E = 0.08026	= 1483.2
Onshore own use	-10,860					
		-10,860 **D**			D/E = 0.005157	see Table 3.2
Input to storage (-)	16,975					
		16,975				
Net supply for onshore consumption		2,105,803 **E**				
Other inputs						
a) Onshore electricity use* **						
- natural gas extraction		85.56 **F**	F/B = 0.000036			
- delivery		936 **G**			G/E = 0.00044	
b) Onshore gas oil use		2,258 **H**			H/E = 0.00107	

* 133,627 TJ (3.444 m³) - Table 24, apportioned between crude oil and natural gas extraction
** Calorific value of natural gas = 54.1144 MJ/kg
*** 1976.4 TJ - Table 48, apportioned between onshore crude oil and natural gas extraction

3.4.1.1 Air emissions from the combustion of natural gas

Natural gas is burned as a fuel during the operations *Natural gas processing*, *Natural gas delivery* and *Natural gas use*. The unit air emissions during combustion are shown in Table 3.2

Table 3.2 Unit air emissions for the combustion of natural gas/ mg			
Emission type	**per 0.02230 MJ** *Natural gas processing*	**per 0.005157 MJ** *Natural gas delivery*	**per MJ** [47] *Natural gas use*
Dust	1.73	0.40	77.55
CO_2	1,133.29	262.08	50,820.00
SO_x	0.26	0.06	11.88
NO_x	16.20	3.75	726.66
HC	10.28	2.38	460.88
CO	0.01	0.00	0.33
CH_4	0.07	0.02	3.10

3.4.1.2 Gross energy for the production and supply of natural gas

The gross energy requirement for the production and delivery of 1 MJ natural gas in the ground to the consumer, calculated from the above input values, is shown in Table 3.3 below.

Table 3.3 Gross energy for the production of natural gas MJ				
Production & delivery energy MJ	**Delivered energy MJ**	**Feedstock energy MJ**	**Total energy MJ**	**Production efficiency %**
0.1125	1.0000	0.0000	1.1125	89.89

The production efficiency, η, is calculated as:

$$\eta = \frac{\text{Total delivered energy}}{\text{Total primary energy input}} \times 100$$

$$= \frac{1}{1.1125} \times 100$$

$$= 89.89\,\%$$

3.4.2 UK grid electricity supply

For any given fuel the process sequence for the production and delivery of electricity may be represented by the simplified flow chart shown in Figure 3.1. Moreover, for each fuel used, the overall efficiency for the production and delivery of electricity, η, has already been defined in Section 3.3 as:

$$\eta = \alpha_1 . \alpha_2 . \alpha_3 . \alpha_4$$

However, grid electricity from the public supply is a blend of electricity produced from different fuels, each with its own production efficiency, and may include imported electricity. The overall average production efficiency, E, depends on the efficiency of electricity production from each fuel and the size of its contribution to the grid. Details of the fuel inputs to electricity generation and supply for 1991, and a further breakdown calculating the gross energy and overall efficiency for production and delivery are shown in Table 3.4.

Table 3.4 Electricity generated and supplied (TWh) 1991* Major generating companies plus autoproducers
Numbers may not agree because of rounding errors

	Thermal				**Non-thermal**			
	Coal + others	**Heavy fuel oil**	**Natural gas**	**Man' gas**	**Nuclear**	**Hydro & wind**	**Imports**	**Total**
Fuel input **A**	587.437	83.708	13.692	7.409				
Electricity generated **B**	208.992	30.345	4.132	1.928	70.543	6.865		322.805
Less own use	10.409	1.511	0.206	0.096	7.782	0.107		-20.111
Electricity supplied gross	198.583	28.834	3.926	1.832	62.761	6.758		302.694
Less use in pumped storage	1.391	0.202	0.027	0.013	0.439	0.037		-2.109
Electricity supplied net **C**	197.192	28.632	3.899	1.819	62.322	6.721		300.585
Plus net imports							16.422	16.422
Total available to grid **D**								317.007
Less transmission & distribution losses								-26.152
Electricity available to energy sector & final users **E**								290.855
Less energy sector consumption								- 9.794
Total electricity to final users								281.061
Efficiency of fuel production & supply $\alpha_1.\alpha_2$ - from Table 3.5	0.9700	0.8740	0.8989	0.8271				
Generating efficiency** α_3 = **B/A**	0.3558	0.3625	0.3018	0.2602	0.3500	0.8000		
Efficiency of net supply **F = C/B**	0.9435	0.9435	0.9435	0.9435	0.8835	0.9790		
Transmission & distribution efficiency **G = E/D**								0.9175
Overall distribution efficiency α_4 = **F x G**	0.8657	0.8657	0.8657	0.8657	0.8106	0.8983		
$\eta = \alpha_1.\alpha_2.\alpha_3.\alpha_4$	0.2986	0.2743	0.2348	0.1863	0.2837	0.7186	0.3563	
Fractional input to grid ρ	0.6220	0.0903	0.0123	0.0057	0.1966	0.0212	0.0518	
Primary fuel requirement ρ/η (Gross energy)	2.0829	0.3293	0.0524	0.0308	0.6930	0.0295	0.1454	3.3632
Average production efficiency, E, = 1/Gross energy = 1/3.3632 =								0.2973

* Digest of UK Energy Statistics 1993 Table 48
OECD Energy Statistics Of OECD countries 1991-1992 p230
OECD *Electricity Information* 1993

** Notional fuel production, supply and generating efficiencies ($\alpha_1.\alpha_2.\alpha_3$)[47,59] : Hydro = 0.8000, Nuclear = 0.3500

3.4.3 Gross inputs and outputs associated with fuel production, delivery and use

Complete inventories of the gross inputs and outputs associated with fuel production, delivery and use are shown in Appendices 1, 2 and 3. The fuel production and delivery efficiencies are of particular interest and may be derived from the gross energy inputs as shown in Table 3.5 below.

Table 3.5 Gross energies for various fuels/ MJ

Fuel	Quantity	Production & delivery energy A	Delivered energy B	Gross energy C = A + B	Production & delivery efficiency % B/C
Coal - average industrial (UK)	1 kg	0.98	28.01	28.99	96.62
Coal - power station average	1 kg	0.77	25.01	25.78	97.00
Coke	1 kg	5.02	25.42	30.44	83.51
Grid electricity	1 kWh	8.51	3.60	12.11	29.73
Natural gas	1 therm	11.86	105.44	117.30	89.89
Manufactured gas	1 therm	22.04	105.44	127.48	82.71
Heavy fuel oil	1 litre	5.91	40.98	46.89	87.40
Medium fuel oil	1 litre	5.90	40.92	46.82	87.40
Light fuel oil	1 litre	5.79	40.18	45.97	87.40
Gas oil	1 litre	5.46	37.84	43.30	87.40
Kerosine	1 litre	5.27	36.53	41.80	87.40
Diesel	1 litre	5.44	37.71	43.15	87.40
Gasoline	1 litre	5.19	35.97	41.16	87.40
LPG propane	1 kg	7.32	50.00	57.32	87.23
LPG butane	1 kg	7.22	49.30	56.52	87.23
Lubricating oil	1 litre	5.79	40.18	45.97	87.40
Grease	1 kg	6.14	42.60	48.74	87.40

Chapter 4

TRANSPORT

4.1 Introduction

Transport operations play a vital and all pervading role in most industrial operations, providing an essential link in the supply of raw materials or semi-finished goods to the manufacturer, and, after processing, in the delivery of finished goods to the consumer. As a consequence they are an important element in the life-cycle inventories of extended industrial systems and cannot be overlooked.

The gross inputs and outputs associated with transport systems may be considered as arising from three separate contributions.

1. The fuel energy required to power the vehicle, which represents the largest proportion of energy.
2. The energy and materials required to construct and maintain vehicles.
3. The energy and materials needed to construct and maintain transport facilities such as roads and railway tracks.

Earlier reports have focused narrowly on the energy requirements of transport, [7,43,60,61,62] but the purpose of this chapter is to broaden the perspective by incorporating all the above inputs and outputs into the life-cycle inventories of the road, rail and waterborne freight transport systems used by the processes described in this research. Of these, road transport is the most important in terms of goods moved (tonne.km), and since the preparation of the life-cycle inventories is similar for all forms of transport, will be considered as an example in the following pages. The results of the life-cycle inventory calculations for the three forms of transport are shown in Appendices 4, 5 and 6.

4.2 Road transport

4.2.1 Direct fuel consumption

The direct fuel consumption of road vehicles depends on a number of inter-related factors, the most important of which are speed, payload, and gross vehicle weight. Ideally, fuel consumption figures should relate to a particular type of vehicle operating under a known conditions of speed, loading etc. However, because of the wide variations in speed and type of service, it is convenient to consider 'average' figures. The figures used in this work are derived from published [63, 64] or confidential sources, and based on a mix of urban and motorway conditions with vehicles carrying a maximum payload. Table 4.1 gives details of gross fuel consumption for the different types of commercial vehicles. From Table 4.1 it is clear that increasing vehicle size, measured in terms of maximum payload or gross vehicle weight, produces a considerable increase in fuel consumption (MJ/vehicle km). If the fuel consumption data are plotted against maximum payload as shown in Figure 4.1 it would appear that larger vehicles, particularly articulated vehicles, are less energy efficient. However, if fuel consumption expressed in terms of MJ/tonne.km is re-plotted as shown in Figure 4.2, it is clear that the reverse is true and larger vehicles are much more energy efficient. Similar conclusions have been reported by Boustead and Hancock [43] albeit with slightly higher fuel consumption.

Fig 4.1 Gross fuel consumption per vehicle-kilometre vs maximum payload for diesel road vehicles

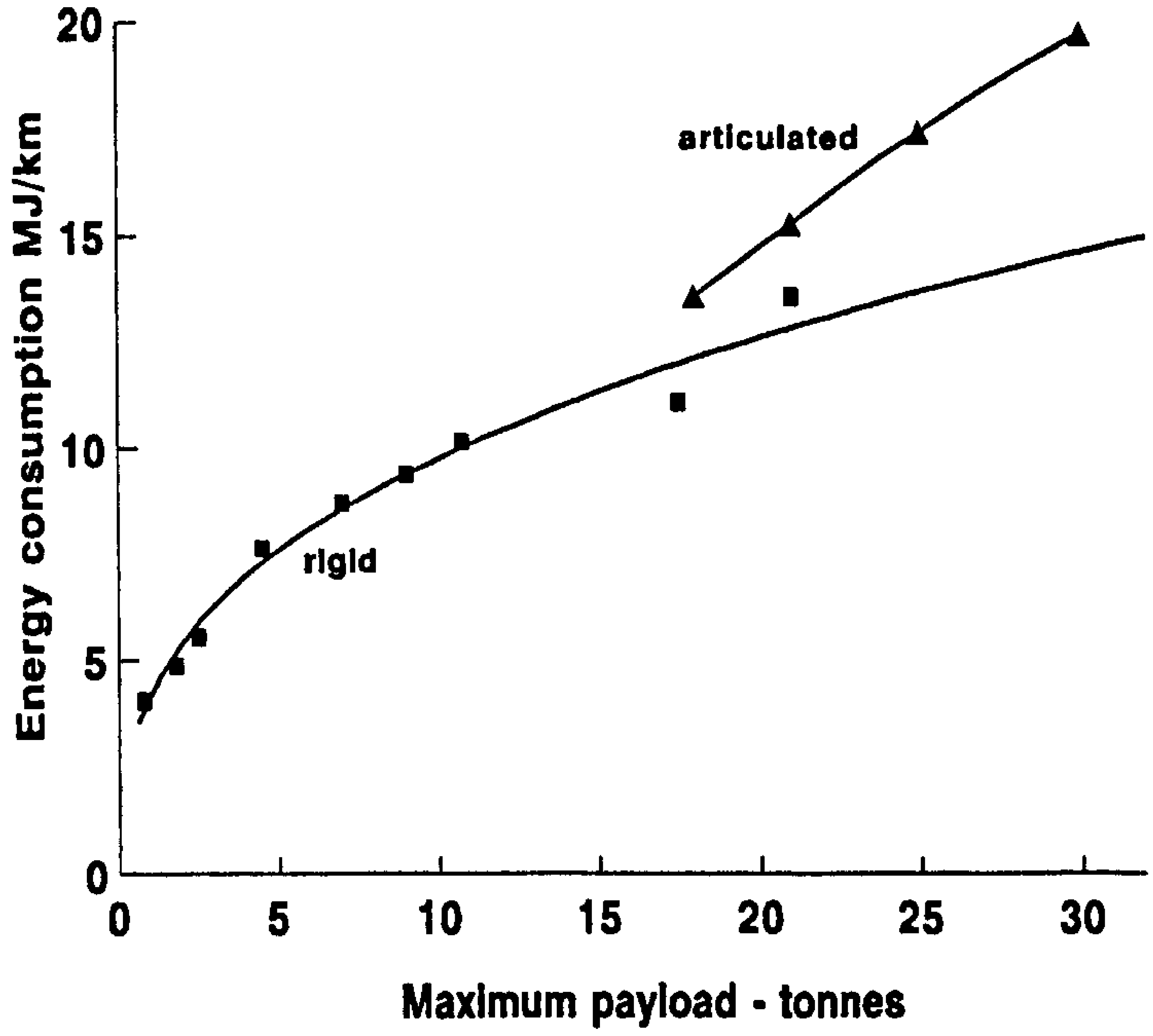
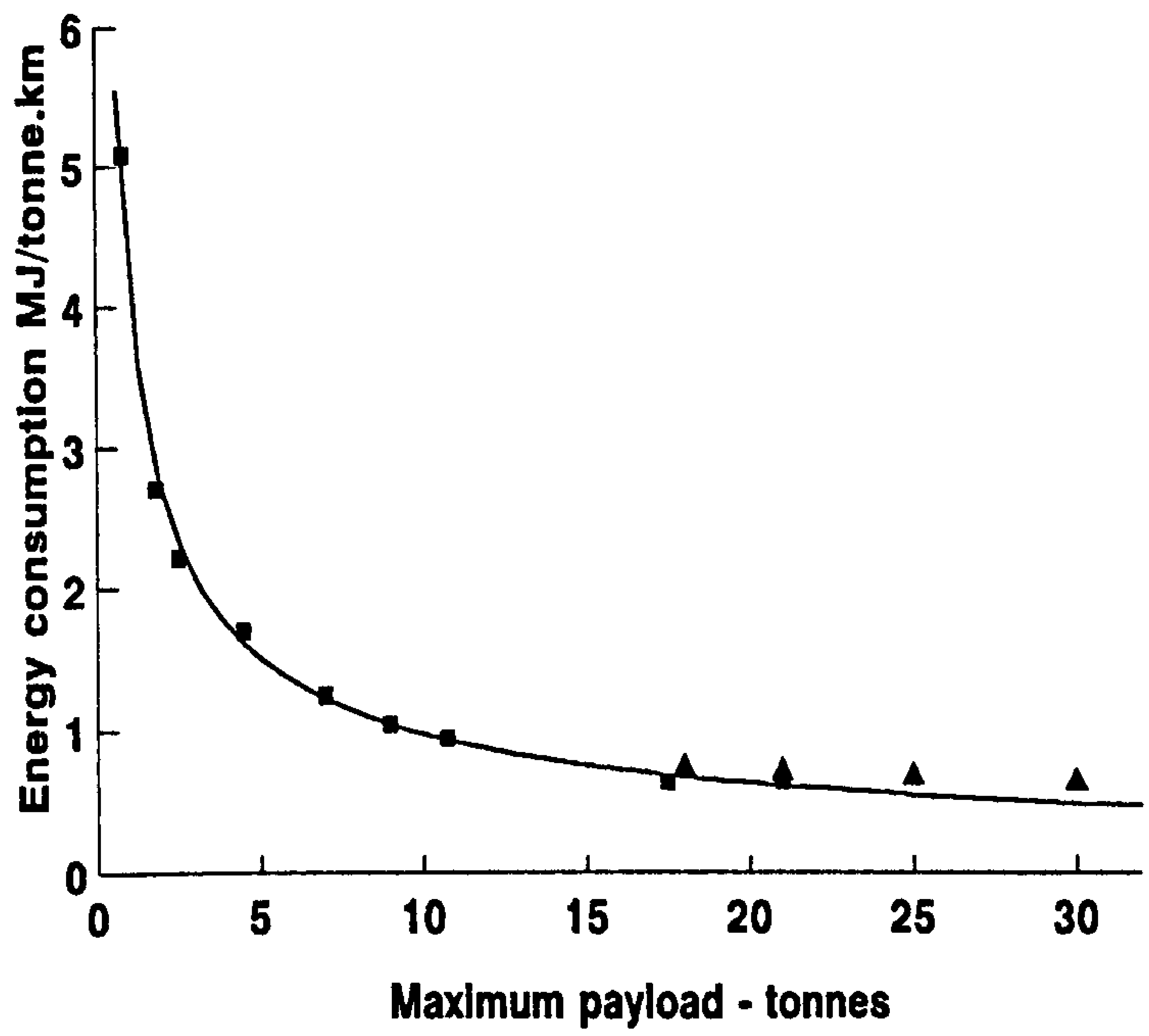


Fig 4.2 Gross fuel consumption per tonne-kilometre vs maximum payload for diesel road vehicles



It is useful, therefore, at this point to consider the choice of units when defining the energy requirements of transport. The most commonly used unit is MJ/tonne.km. However, energy values expressed in this way are sensitive to variations in load. This is particularly the case for road transport, where it is generally more convenient to express energy requirements as MJ/vehicle km. In contrast, the energy requirements of rail and waterborne transport are less load sensitive, and for these systems it is more usual to retain the former unit and to calculate energy consumption as MJ/tonne.km.

4.2.2 Vehicle construction inputs

Notional values for construction inputs have been estimated by adopting the procedure used by Makhijani and Lichtenberg.[5] If it is assumed that 80 % of the mass of a typical unladen vehicle is steel, then a reasonable approximation for the construction energy can be made by assuming that the remaining 20 % is also steel. It is argued that the gross energy requirement of the remaining 20 % of materials, copper, aluminium, alloys and plastics, plus an allowance for the assembly energy, approximates to the same value obtaining if these materials are considered as steel. Estimated values of the gross construction energies for different vehicles are shown in Table 4.1 on p. 57.

4.2.3 Vehicle maintenance inputs

Vehicle maintenance inputs is a catch-all term for the energy and materials required to service and maintain a vehicle in a safe and roadworthy condition. It includes lubricant consumption, spares usage and garaging. Values for maintenance inputs have been derived from data obtained from published [63, 64] and commercial sources. Details of gross maintenance energies arising from the sources described below are shown in Table 4.1.

4.2.3.1 Lubricants

Values of lubricant consumption have been calculated from data supplied by a large fleet operator. Using these figures it can be shown that 99 % of all oil used for lubrication is consumed by engine oil changes during servicing or for topping up sumps. Gearbox and axle oil account for the remaining 1 %. Grease usage is extremely small representing about 0.5 % of all lubricants in energy terms. Moreover, since engine oil is changed at regular service intervals, there is little variation in lubricant consumption between the different types of vehicle.

4.2.3.2 Spares

The main components that may need replacing during a vehicle's lifetime are large items such as engines, gearboxes and differentials, smaller parts such as batteries and occasional restoration of paintwork and tyres. On modern vehicles major components such as engines or gearboxes usually have a working lifetime well in excess of the vehicle's and will rarely require replacing. For a large fleet the frequency of replacement is likely to be so low that the total production energy of the replaced components per total fleet km is assumed to be negligible. In contrast, paintwork and smaller components such as lead acid batteries will rarely last the lifetime of a vehicle and may need replacing more than once. Tyres have a high gross energy requirement and are frequently replaced, and must therefore be included with paint and lead acid batteries as inventory inputs.

Battery and paint usage by a large fleet operator have been combined with details of battery and paint composition, obtained from commercial sources, to calculate inputs of polypropylene, sulphuric acid, lead and paint.

Tyre usage depends on many variables such as size, route used, position on the vehicle and vehicle type. However, for the purpose of this work, average tyre lifetimes quoted in published literature [63] will be used. Using confidential information from commercial sources detailing the inputs and outputs to radial tyre production, and the assumptions listed below, an estimate of the 'average ' tyre usage per vehicle km has been made.

- the typical tyre usage pattern by commercial vehicles is 2/3 new : 1/3 retread [65]
- the total life of a retreaded tyre is 1.7 times the first life [65]
- the 'average' tyre is considered to be a hybrid based on 2/3 new plus 1/3 retread tyre
- 'average tyre life' = (2/3 x first lifetime) + (1/3 x 1.7 x first lifetime)
- material inputs to produce a 12 R 22.5 tyre of mass 65.56 kg, suitable for use on a 38 tonne articulated vehicle, are based on a typical composition of: 45 % polymers, 23 % carbon black, 22 % steel and 10 % others (eg. sulphur, oils, antioxidants)
- material inputs to retreading are similar by proportion to the quantities used in the tread of the new tyre, less 10 % for incomplete removal of the original tread.
- the manufacturing inputs to produce such a tyre, are considered as 2/3 new tyre inputs plus 1/3 retread tyre inputs
- the 12 R 22.5 tyre is used for all vehicles with adjustments for tyre size (mass)

4.2.3.3 Garaging

Contributions to maintenance from garaging are attributed to

- electricity for lighting and powering tools and equipment
- fuels such as kerosine or natural gas used for space heating

Inventory inputs have been calculated using details of electricity and natural gas consumption obtained from a large fleet operator.

4.2.4 Inputs to the construction and maintenance of transport facilities

Whilst it is desirable in principle to include the inputs and outputs associated with the construction and maintenance of road transport facilities, the major difficulties in making an accurate apportionment between the different road users make it necessary to ignore these contributions.

4.2.5 Gross inputs and outputs

A summary of the gross energy requirements of road transport is shown in Table 4.1. The gross inputs and outputs for the main vehicle types used in this research are detailed in Appendices 4, 5 and 6.

Table 4.1 Gross fuel, maintenance and construction energies for different types of road vehicles MJ/vehicle km (Totals may not agree because of rounding errors)

Vehicle type/payload	Fuel energy	Maintenance energy				Construction energy	Gross energy
		Lubrication	Tyres	Garaging	Paint & batteries		
Rigid < 1 tonne	3.42	0.04	0.20	0.34	0.01	0.28	4.30
Rigid (1-2) tonne	4.88	0.04	0.37	0.34	0.01	0.37	6.01
Rigid (2-3) tonne	5.11	0.04	0.49	0.34	0.01	0.59	6.59
Rigid (4-5) tonne	7.19	0.04	0.61	0.34	0.01	0.61	8.82
Rigid (5-8) tonne	8.71	0.04	0.57	0.34	0.01	0.91	10.59
Rigid (8-9) tonne	9.04	0.04	0.53	0.34	0.01	0.95	10.92
Rigid (10-12) tonne	10.16	0.04	0.52	0.34	0.01	0.63	11.70
Rigid (13-21) tonne	12.31	0.04	1.20	0.34	0.01	0.87	14.77
Rigid 17.5 tonne concrete mixer	22.16	0.04	1.05	0.34	0.01	0.85	24.46
Rigid tipper 4 tonne	8.71	0.04	0.38	0.34	0.01	0.78	10.27
Rigid tipper 10.75 tonne	10.16	0.04	0.95	0.34	0.01	0.84	12.34
Rigid tipper 16.5 tonne	12.19	0.04	1.05	0.34	0.01	1.27	14.91
Rigid tipper 21 tonne	15.24	0.04	1.42	0.34	0.01	1.47	18.53
Articulated 17 tonne	13.54	0.04	0.78	0.34	0.01	0.67	15.39
Articulated (18-25) tonne	16.20	0.04	1.11	0.34	0.01	0.99	18.70
Articulated 30 tonne	19.70	0.04	1.47	0.34	0.01	1.12	22.69

Garaging includes grid electricity & natural gas use
Construction includes steel

The gross fuel energy shown in Table 4.1 refers to vehicles carrying a maximum payload. However, many vehicles carry partial loads, with some delivering a full load and returning empty. Moreover, vehicles carrying low density loads, such as PVC pipes, may exceed the regulatory volume limits before exceeding the permitted axle loading. Therefore, for many vehicles it is difficult to estimate the fuel input. Thus, for simplicity, unless otherwise stated, fully laden vehicles are assumed throughout this research. For unladen vehicles the fuel consumption is calculated using the following empirical relationship.[43]

Unladen fuel consumption = 0.7 x Fully laden fuel consumption

Chapter 5

ECO-PROFILE OF BUILDING MATERIALS

5.1 Introduction

The purpose of this chapter is to complete an eco-profile analysis for the different building materials used in modern house construction. For convenience these inputs may be grouped together as follows.

- Mineral compounds such as sand, limestone, clay, gypsum and others
- Limestone products such as hydrated lime and asphalt
- Cement
- Structural clay products
- Concrete and mortar products
- Plaster products
- Flat glass and glass fibre wool
- Timber and timber products
- Metals
- Plastics
- Miscellaneous products such as pulverised fuel ash

Although the production detail will vary for each material or product, the repetitive process sequence - *Processing - Packaging - Delivery*, as shown in Figure 2.12, is common to all. It is proposed to consider the detailed production of cement as an example, and to record schematic flow diagrams and the gross inputs and outputs associated with the remaining materials or products in Appendices 7 to 86. A further aim is to discuss the basis on which eco-profiles between different building types and between alternative building materials may be considered.

5.2 Cement production

The starting materials for cement production are minerals containing calcium carbonate - $CaCO_3$, silica - SiO_2, alumina - Al_2O_3, and iron oxide - Fe_2O_3. The two main raw materials are limestone and clay or limestone and marl, although in the plant studied in this report a mixture of limestone, sand and shale was used.

The manufacturing details for cement production have been described elsewhere.[34, 66] Although no two plants are identical they all involve the following common stages.

1. A preliminary reduction in the particle size of the raw materials as a preparation for intimate mixing.
2. A further reduction in particle size during milling as the raw materials are mixed and blended to produce a raw feed of uniform chemical composition. Cement is said to be manufactured by the *wet or dry process* depending on whether water is included with the raw materials at this stage, although *semi-wet* and *semi-dry* variants exist with a medium moisture content. The raw mix is known as *'slurry'* in the wet process and *'raw meal'* in the dry process. The distinct advantage of the dry process is the saving of energy by eliminating the need to evaporate unnecessary water in the kiln.
3. Heating of the raw mix in a kiln where any water is driven off and calcium carbonate is dissociated to form calcium oxide, which reacts at high temperatures with the oxides of aluminium, silicon, and iron to form cement *clinker*.
4. Addition of gypsum - $CaSO_4$, to the clinker to retard the setting time of the finished cement, followed by a milling stage to grind the clinker to a specified size.
5. Packing and delivery of the finished cement.

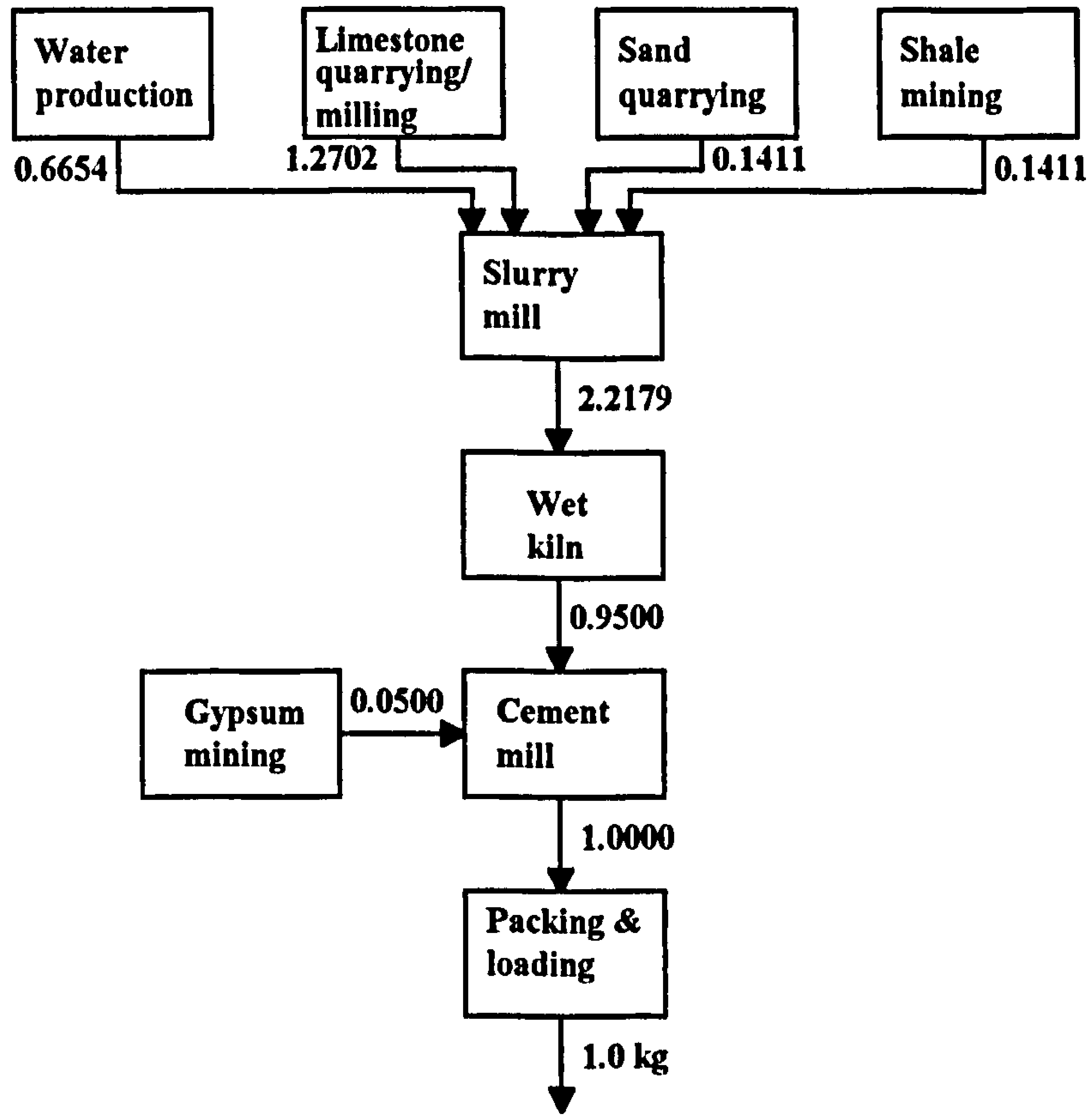


Figure 5.1 Schematic flow diagram for the production of cement by the wet process from raw materials in the ground. All flows are in kg

5.2.1 Process details

The following discussion relates to processes within the cement works and does not include the extraction, processing and delivery of raw materials other than water. For the site used in this study about 680,000 tonnes of cement are produced annually, of which 49.23 % is produced using two wet kilns and 50.77 % from one dry kiln running parallel with each other. Raw material supplies of limestone, sand and shale are delivered an average distance of 9 km by road, and water is pumped a distance of 6.4 km from a nearby borehole. Simplified schematic flow diagrams showing mass flows for both the wet and dry processes are shown in Figures 5.1 and 5.2 respectively.

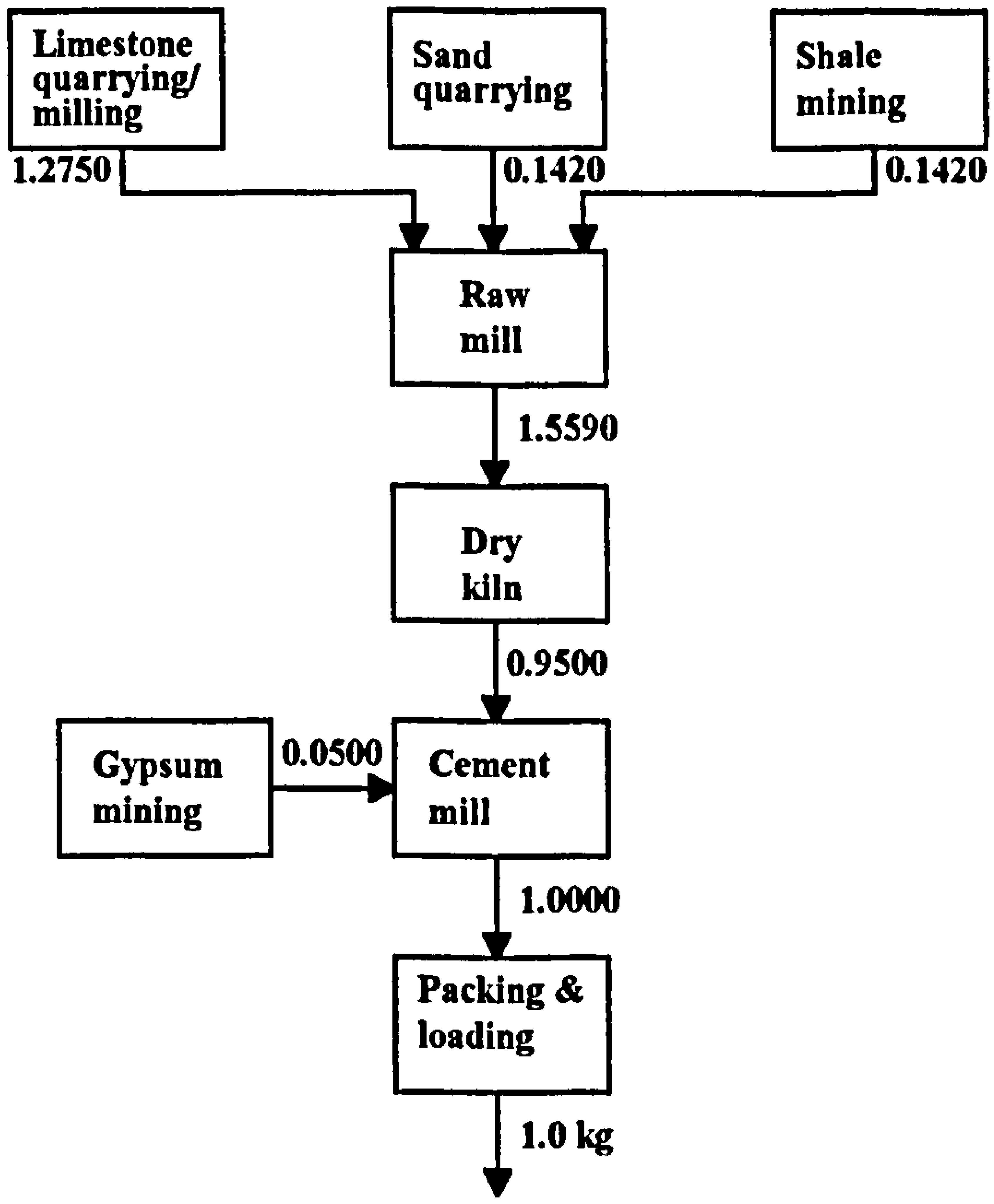


Figure 5.2 Schematic flow diagram for the production of cement by the dry process from raw materials in the ground. All flows are in kg

5.2.1.1 Raw materials inputs

The mass flows shown in Figures 5.1 and 5.2 have been calculated on the following basis.

1. The typical chemical composition of a raw mix is approximately 80 % calcium carbonate, 14.5 % silicon oxide, 3 % aluminium oxide, 1.3 % iron oxide and smaller amounts of magnesium, potassium and sodium oxides, which is provided for in the plant investigated by a limestone : sand : shale ratio of 9 : 1 : 1.
2. The water content of the fluid slurry in the wet process is 30 %
3. The loss on ignition during the calcination process in the kiln is 40 %
4. 10 % by mass of coal used as kiln fuel is deposited as ash in the clinker
5. The gypsum content of the finished cement is 5 %

In addition, both wet and dry processes consume 0.7703 kg of coolant water per kg of finished cement.

5.2.1.2 Direct fuel consumption

Tables 5.1 and 5.2 provide details of direct fuel consumption, averaged over twelve months, for the production of cement by the wet and dry processes respectively.

Table 5.1 Direct fuel consumption - wet process MJ/kg				
	Fuel			
	Electricity	Heavy fuel oil	Coal	Total
Feed processing				
Limestone crushing	0.0083			0.0083
Shale crushing	0.0013			0.0013
Slurry mill	0.1757			0.1757
Clinker production - kiln				
Coal mill	0.0178			0.0178
Kiln power & fuel	0.0826	0.2140	4.6445	4.9411
Cement processing				
Drag chain to cement mill	0.0043			0.0043
Cement mill (o.p.c)	0.1656			0.1656
Loading packing	0.0093			0.0093
Ancillary processes				
Crane store	0.0028			0.0028
Heating & lighting	0.0107			0.0107
Workshops & labs	0.0053			0.0053
Offices & canteen	0.0006			0.0006
Transport depot	0.0009			0.0009
Water pumps	0.1854			0.1854
Total	0.6705	0.2140	4.6445	5.5291

Table 5.2 Direct fuel consumption - dry process MJ/kg				
	Fuel			
	Electricity	Heavy fuel oil	Coal	Total
Feed processing				
Limestone crushing	0.0084			0.0084
Shale crushing	0.0013			0.0013
Raw mill	0.1235			0.1235
Clinker production - kiln				
Coal mill	0.0140			0.0140
Kiln power & fuel	0.0756	0.0976	3.6613	3.8345
Cement processing				
Drag chain to cement mill	0.0043			0.0043
Cement mill (o.p.c)	0.1656			0.1656
Loading packing	0.0093			0.0093
Ancillary processes				
Crane store	0.0028			0.0028
Heating & lighting	0.0107			0.0107
Workshops & labs	0.0053			0.0053
Offices & canteen	0.0006			0.0006
Transport depot	0.0009			0.0009
Water pumps	0.1008			0.1008
Total	0.5230	0.0976	3.6613	4.2819

5.2.1.3 Transport operations

Cement is delivered to customers by road and rail. The relative proportions delivered in bulk or bagged form, for each mode of transport, are shown in Table 5.3 below.

Table 5.3 Delivery of cement by road and rail			
	% Bulk	% Bagged	Average distance of single journey (km)
Road - 20.0 t payload rigid vehicle	66.7	30.3	46.8
Rail - average load 401.5 t	3	0	161

Road transport inputs

Number of vehicle.km per kg of cement $= \dfrac{46.78 \times 1.7}{20{,}000}$

$= 0.00397$ vehicle.km/kg

(The multiplier of 1.7 arises from fuel saving made by vehicles returning empty [43])

Rail transport inputs

Number of tonne.km per kg of cement $= \frac{401.5 \times 161 \times 2}{401.5 \times 1{,}000}$

$= 0.322$ tonne.km/kg

5.2.1.4 Air emissions

The air emissions associated with the production of cement arise from as follows.

1. Dust produced from the comminution, handling and processing of the material components which finally form cement.
2. Carbon dioxide and other gases produced by thermochemical reactions involving raw materials in the kiln.
3. Combustion products from coal and heavy fuel oil use in the kiln.

It is very difficult to obtain accurate reliable data from producers and in the circumstances estimated air emissions have been calculated as shown below.

a) Dust

Estimates for dust emissions at various points in the cement plant have been made using reference data for air and gas volumes vented for the purposes of cleaning and filtering, [66] in conjunction with the UK regulatory upper emission limits.[67] All gas volumes are expressed as being measured at 15°C and 1 atmosphere pressure without correction for water vapour content.[67]

Using the dust emissions from the wet process kiln as an example:

Regulatory upper limit = 460 mg/m^3 of vented air

Vent rate of exit gases from wet process kiln = 2.8 - 3.5 m^3/kg clinker

Assuming a vent rate of 3.0 m^3/kg clinker, the upper limit dust emission is

= (3 x 460) = 1,380 mg per kg clinker

or = 1,311 mg per kg cement

The total estimated dust emissions for the wet and dry processes are shown in Table 5.4

Table 5.4 Dust emissions produced during cement production - mg/kg cement		
	Wet process	**Dry process**
Shale crushing	0	0
Raw mill		1,793
Coal mill	85	134
Kiln	1,311	874
Cement mill	1,150	1,150
Packing/loading	168	168
Total	2,715	4,120

b) Emissions produced by thermochemical changes to raw materials in the kiln

Carbon dioxide production

If the input of limestone is considered as 100 % calcium carbonate then the production of carbon dioxide from the thermal dissociation taking place during calcination may be calculated from the stoichiometry of the equation:

$$CaCO_3 \rightarrow CaO + CO_2$$

From the equation it can be seen that 1 mole (100 g) of calcium carbonate produces 1 mole (44 g) of carbon dioxide on dissociation. Thus, an input of 1.2702 kg of limestone (wet process - see Figure 5.1 on p. 61) will produce

$$1.2702 \times \frac{44}{100} \text{ kg of carbon dioxide}$$

$$= 0.5589 \text{ kg}$$

Similarly, an input of 1.275 kg of limestone (dry process) will produce 0.5610 kg carbon dioxide.

Other emissions

Other possible emissions include sulphur dioxide and hydrogen sulphide from sulphide impurities, and hydrogen fluoride from fluorides such as calcium fluoride. However, in the absence of plant data it is only possible to estimate an upper limit for controlled emissions such as hydrogen sulphide. Using the regulatory upper limit of 5 ppm v/v for hydrogen sulphide,[67] and a vent rate of 2.0 and 3.0 m^3/kg clinker for the dry and wet rotary kilns respectively, the hydrogen sulphide emissions may be calculated as:

Dry process = 13.45 mg/kg cement

Wet process = 20.19 mg/kg cement

c) Products arising from the combustion of fuels

The gaseous emissions from the combustion of coal and heavy fuel oil used as kiln fuels, as shown in Table 5.5, have been calculated from reported emission data for fuel use.[47]

Table 5.5 Total air emissions from the combustion of coal and heavy fuel oil used as kiln fuels in cement production - mg/kg cement

Emission type	Wet process	Dry process
dust	1,859	1,465
CO	303	238
CO_2	383,814	297,375
SO_x	4,945	3,798
NO_x	1,433	1,106
HCl	93	73
HF	3	3
HC	91	65
CH_4	5	4

5.2.1.5 Emissions to water

The only reported emissions to water are discharges of suspended solids amounting to 50 mg/litre, which may be apportioned to the wet and dry processes respectively as:

Wet process = 9.48 mg/kg cement

Dry process = 5.08 mg/kg cement

5.2.1.6 Solid waste

Apart from dust emissions, very little solid waste is acknowledged during cement production, any filtered solid material being recycled. However, 600 mg/litre of solid matter is filtered from the water supply, which, when apportioned between the wet and dry processes becomes:

Wet process = 861.42 mg/kg cement

Dry process = 462.18 mg/kg cement

5.2.1.7 Gross inputs and outputs

Since cement produced by the wet process is indistinguishable from cement produced by the dry process, it is appropriate to calculate weighted mean values for the inputs and outputs associated with each process. It is these values that will be used later in the calculation of the gross inputs and outputs associated with cement based construction materials such as concrete. The gross energy requirements for the production and delivery of cement by the wet and dry processes are shown in Table 5.6 in terms of the contributing operations. The gross inputs and outputs associated with the production and bulk road delivery of cement are shown in Table 5.7.

Table 5.6 Gross energy requirements for the production & bulk delivery of cement MJ/kg

Operation	Wet process	Dry process	Weighted average - wet/dry processes [1]	%
Raw materials - processing & delivery	0.1919	0.1926	0.1923	2.86
Feed processing	0.6231	0.4477	0.5340	7.95
Clinker production - kiln				
- Coal milling	0.0597	0.0471	0.0533	0.79
- Kiln fuel	5.0519	3.9012	4.4677	66.47
- Kiln power	0.2778	0.2542	0.2658	3.95
Cement processing	0.6027	0.6027	0.6027	8.97
Ancillary processes	0.6919	0.4072	0.5473	8.14
Delivery - road transport			0.0587	0.87
Total	7.4989	5.8526	6.7218	100.00

[1] based on wet/dry ratio of 49.23/50.77

From Table 5.6 it is clear that fuel usage makes the largest contribution to the overall gross energy requirement, and, as expected, the need to drive water from the raw slurry before clinker formation makes the wet process more energy intensive than the dry process. These results compare favourably with the 1980 industry-wide average gross energy requirement of 6.75 MJ/kg before delivery.[34]

Table 5.7 Gross inputs and outputs associated with the production and bulk road delivery of cement /kg (Totals may not agree because of rounding errors)

Energy	**MJ**
Electricity - production & delivery	1.51
Electricity - delivered	0.64
Oil fuels - production & delivery	0.03
Oil fuels - delivered	0.24
Other fuels - production & delivery	0.15
Other fuels - delivered	4.15
Total energy	6.72

Primary fuels	**MJ**
Coal	5.55
Oil	0.51
Gas	0.07
Hydro	0.03
Nuclear	0.55
Total fuels	6.71
Primary feedstocks	**MJ**
Coal	0.01
Total feedstocks	0.01
Total fuels & feedstocks	6.72

Raw materials	**mg**
Bauxite	4
Gypsum	50,000
Fe-Mn	2
Iron ore	700
Limestone	1,272,900
Met coal	288
Sand	141,558
Water	2,145,800
Shale	141,557
Air	42
Sulphur	3

Water emissions	**mg**
COD	1
Acid	4
Metals	1
Suspended solids	4,933
HC	1

Solid waste	**mg**
Mineral waste	71,370
Slags/ash	3,018
Industrial waste	142,192

Air emissions	**mg**
Dust	6,051
CO	433
CO_2	1,039,000
SO_x	6,141
H_2S	17
NO_x	1,889
HCl	110
HF	5
HC	209
CH_4	1,459

5.3 Basis for comparison between eco-profiles

Later in this work it is proposed to make comparisons between the eco-profiles of the two types of building under consideration (Chapter 7), and between alternative building materials (Chapter 8). The eco-profiles contained in the Appendices provide gross input-output data sets under the headings *Energy*, *Raw materials*, *Air emissions*, *Water emissions*, and *Solid waste*. It is useful to establish the basis on which comparisons are to be made for entries under these headings.

Whilst it may make sense to compare aggregate gross energy totals, it is meaningless and incorrect to compare aggregate totals of raw material inputs, air emissions, water emissions and solid waste. Any comparison must be between identical inputs and outputs. However, since it is unmanageable to consider all possible comparisons, it is necessary to be selective and to choose major or significant inputs or outputs.

5.3.1 Gross energy

Gross energy inputs may be compared either in terms of the fuel producing industries or as primary fuels and feedstocks as discussed in Section 2.8.1. However, it is proposed to use the gross energy totals as the basis for comparison since these values represent the total energy resources to be extracted from the ground from all sources to support the systems being compared.

5.3.2 Raw materials

Comparisons between raw material inputs are relatively simple for systems consuming similar materials; for example, the three bedroom bungalow and the four bedroom detached houses. It is clear from Appendix 87 that in these cases the two inventories share many common raw materials in roughly similar proportions. Water apart, sand, clay and limestone are the most dominant inputs and are selected for the purpose of comparison. Water inputs, although significant, are not included for comparison since water is a renewable resource and apart from small quantities involved in chemical reactions is naturally re-cycled.

In contrast, it is meaningless to compare the raw material inputs to systems producing alternative building materials when the inventories contain different dominant materials. For example, consider the eco-profiles for anodised aluminium and PVC window frame production, Appendices 62 and 73 respectively. Ignoring water inputs, the dominant input to aluminium window frame production is bauxite, whilst the dominant inputs to PVC window frame production are crude oil feedstock and sodium chloride. Since it is impossible to compare bauxite with crude oil feedstock or sodium chloride, it is pointless to consider such comparisons.

5.3.3 Air emissions

It is proposed to restrict comparisons between air emissions to carbon dioxide and sulphur dioxide only. Carbon dioxide is selected since it is by far the most abundant air emission, but also because it is subject to regulatory control as a known greenhouse gas. Sulphur dioxide is chosen because it is also subject to regulatory control as a precursor of acid rain.

5.3.4 Water emissions

Examination of the eco-profiles detailed in Appendices 7 - 92 shows that with few exceptions discharges of suspended solids are consistently the most significant water emission. For this reason it is proposed to limit comparisons between water emissions to suspended solids only.

5.3.5 Solid waste

Although considerable quantities of solid waste are recorded in the above eco-profiles, most is used as landfill, returned to earth or used for other purposes such as hardcore. Apart from small quantities of toxic chemicals, solid waste is relatively unimportant and is not subject to regulatory control. Consequently it is not proposed to include solid waste as a basis for comparison.

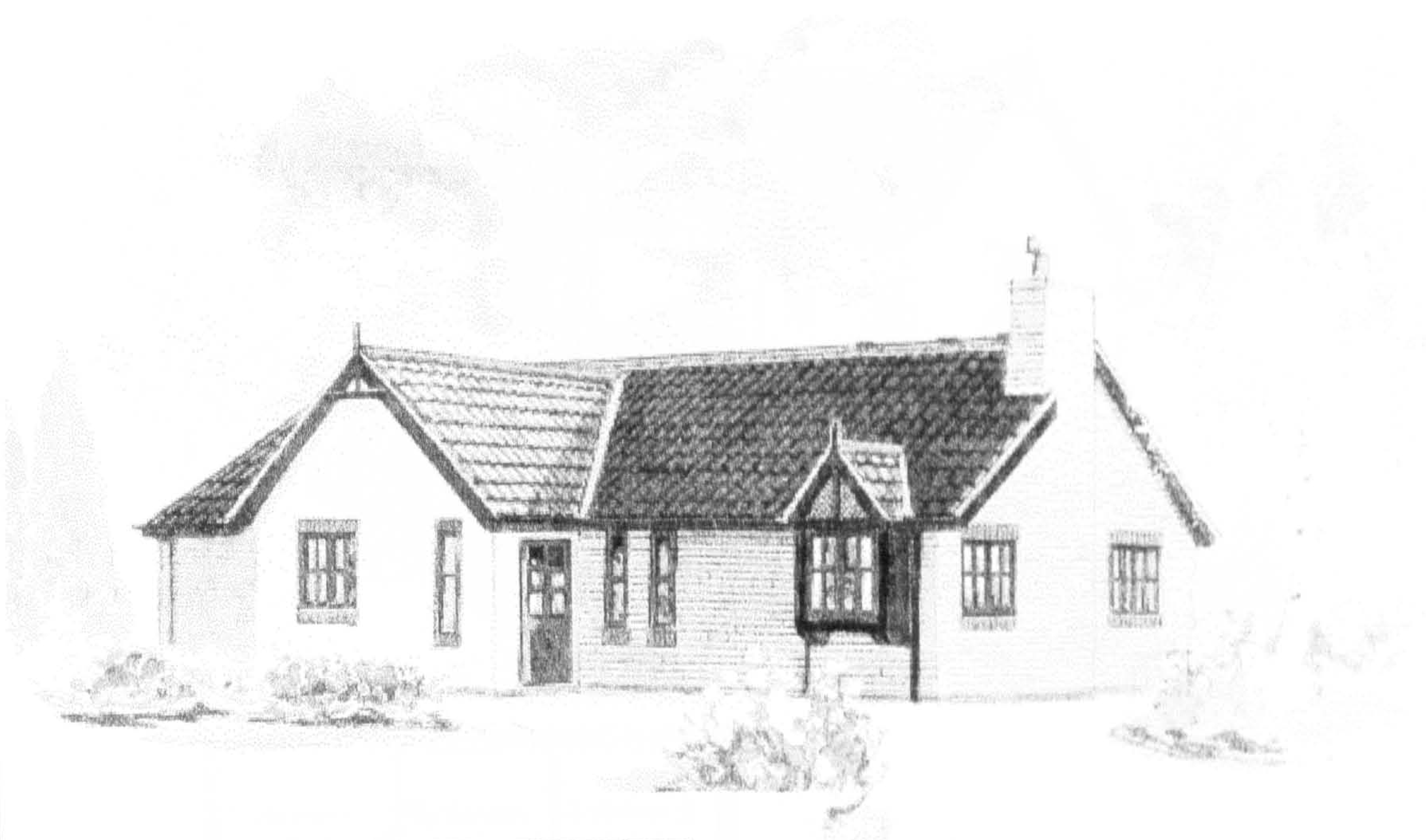
Chapter 6

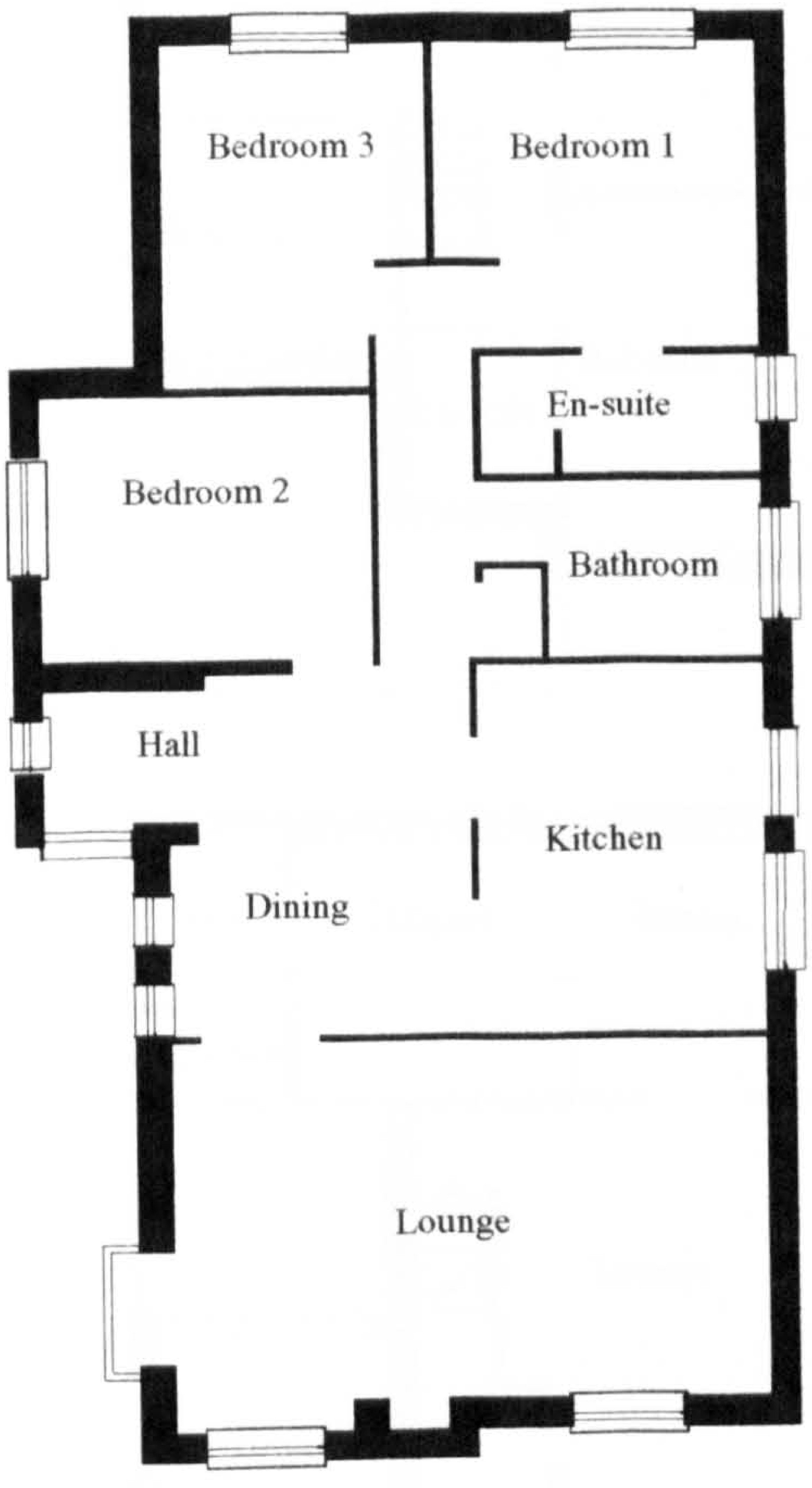
MATERIAL INPUTS TO BUNGALOW AND DETACHED HOUSES

6.1 Introduction

The purpose of this chapter is to examine the building specifications for the two buildings under consideration. Detailed plans and inventories of the material inputs to a three bedroom bungalow house and a four bedroom detached house have been supplied by a reputable construction company. Artistic impressions and floor plans for each building are shown in Section 6.2. The assumptions used to calculate the material inputs to each building are shown in Section 6.3, whilst the material inputs supplied 'as used' by the construction company are detailed in Sections 6.4 and 6.5 respectively.

6.2 Artistic impressions and floor plans



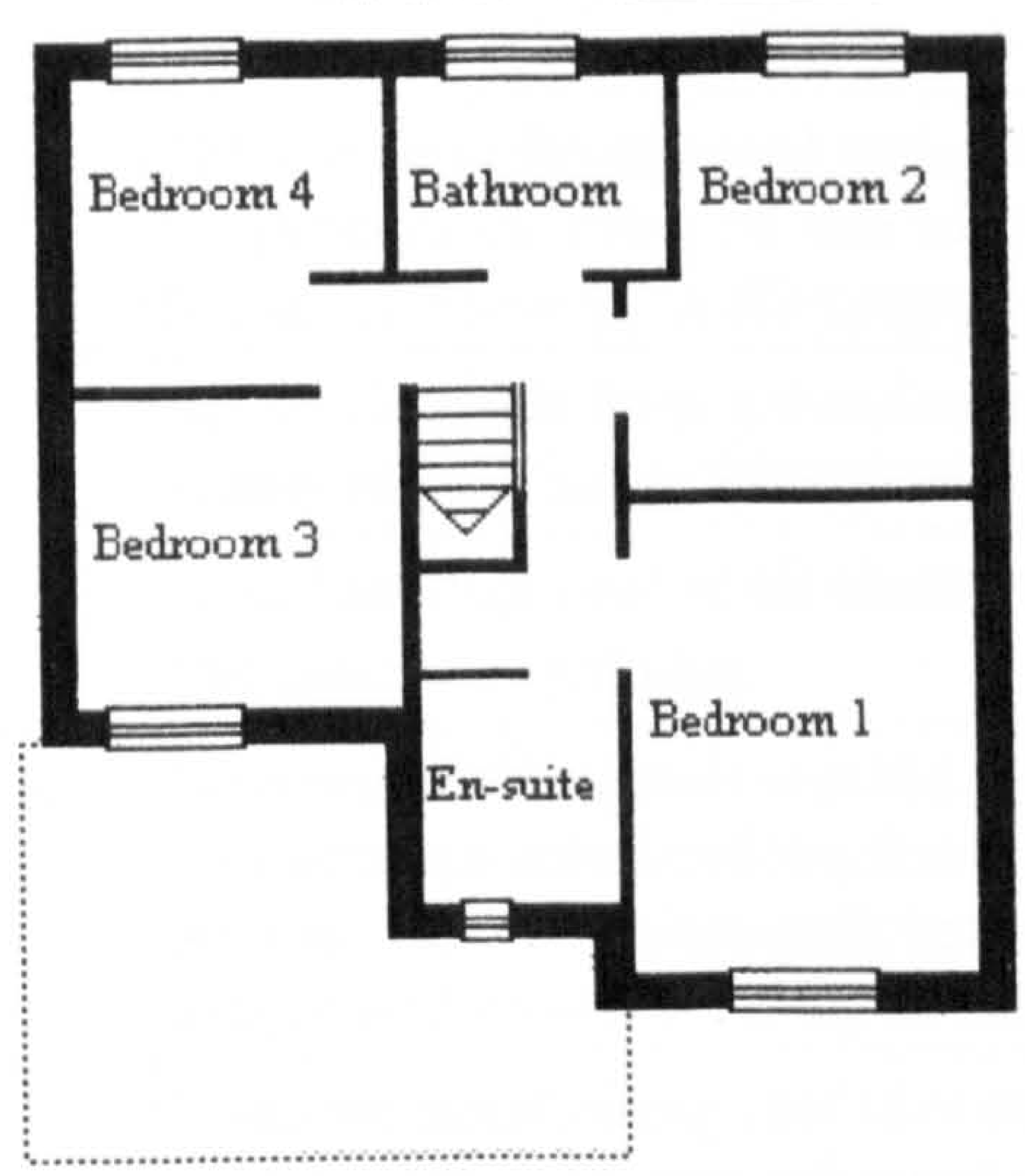


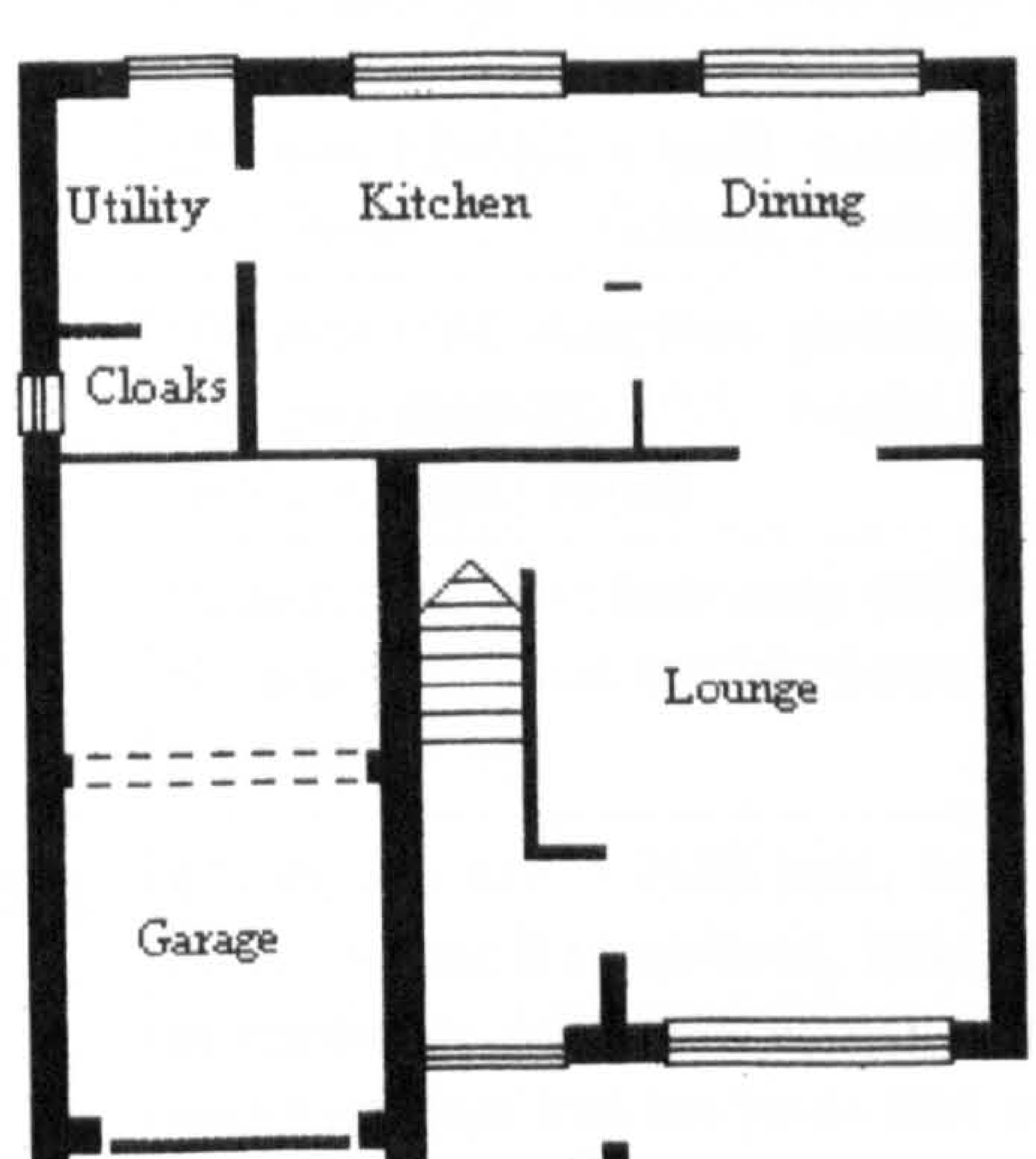
Room sizes (mm)

Lounge	5,944	x	3,251
Dining	3,505	x	3,048
Kitchen	3,505	x	2,870
Bedroom 1	3,251	x	3,150
Bedroom 2	3,353	x	2,667
Bedroom 3	3,353	x	2,591
Bathroom	2,769	x	1,829
En-suite	2,769	x	1,168

Total floor area - 87.0 m^2

Figure 6.1 Floor plan and sketch of three bedroom bungalow





Room sizes (mm)

Lounge	4,699	x	3,810
Dining	2,997	x	2,794
Kitchen	3,302	x	2,997
Utility	1,880	x	1,600
Bedroom 1	4,089	x	2,997
Bedroom 2	3,607	x	2,997
Bedroom 3	2,896	x	2,692
Bedroom 4	2,692	x	2,692
Bathroom	2,388	x	1,676
En-suite	1,981	x	1,676

Total floor area - 122.3 m^2

Figure 6.2 Floor plan and sketch of four bedroom detached house

6.3 Assumptions used in the calculations of material inputs

Table 6.1 Assumptions used in the calculation of the material inputs for the construction of a three bedroom bungalow house and a four bedroom detached house (based on architect's specifications)	
Foundations	Concrete strip footings minimum 200 mm thick, projecting 150 mm to each side of loadbearing walls.
Ground floor	15 mm asphalt floor covering on successive layers of: concrete (100 mm), *visqueen* (polyethylene) damproof membrane, sand (50 mm), and compacted hardcore (150 mm)
External walls	290 mm cavity walls: 100 mm facing brick 50 mm cavity, 140 mm thermal block inner leaf, maximum U value 0.6 W/m^2 °C. Galvanised steel wall ties at maximum 450 mm vertical centres, 900 mm horizontal centres. Cavities filled with weak concrete mix up to ground level. Horizontal damp proof course (dpc) minimum 150 mm above ground level and to vertical cavity closures. Cavities closed at eaves and all openings.
Internal walls	100 mm brick or 100 mm structural block loadbearing walls built off strip foundations and fully bonded to adjoining loadbearing walls.
Internal partitions	75 x 50 mm soft wood studs at 450 mm vertical centres with 12.5 mm plasterboard skimmed to both sides. Built off dpc at ground floor.
Internal finishes	13 mm lightweight plaster and skim to walls. Galvanised bead to all external angles.
External soft wood finish	All exposed softwood treated with 2 coats of stain finish or primer, undercoat and gloss paint.
Eaves and barges	225 x 25 mm fascia board with 9 mm ply eaves soffit projecting 200 mm. 175 x 25 mm barge board on 100 x 38 mm soft wood ladder frame. 38 x 38 mm soft wood batten fixing for 9 mm ply soffit projecting 200 mm.
Lintels/ steelwork	All lintels made from galvanised pressed steel. Minimum 150 mm end bearings. Steel beams and purlins to Structural Engineers design.
Flashings	Lead flashings used at all abutments with minimum 150 mm upstand and minimum 150 mm over roof tiles.
Projecting bay	Standard window built into100 x 50 mm soft wood framing bolted to brick jamb and supported on soft wood brackets. Mild steel straps fixing cill joists to inner-leaf. 60 mm thick fibreglass quilt between framing. 9 mm ply soffit, 19 mm thick soft wood tongue and groove cladding to sides.
Roof	Concrete interlocking roof tiles on 38 x 25 mm soft wood battens. Rafters at 600 mm centres. 100 x 25 mm soft wood diagonal, longitudinal, ceiling and chevron bracing. 30 x 5 mm galvanised mild steel straps at maximum 2 m centres with 75 x 50 mm soft wood blocking noggins fixed to external gable walls at ceiling and roof level. 150 mm fibreglass quilt insulation laid between ceiling members. (maximum U value 0.35 W/m^2 °C). Ceiling finish foil backed 12.5 mm plasterboard and skim.
External plumbing	100 mm PVC deepflow gutters and 68 mm diameter downpipes to back inlet gullies. 100 mm diameter PVC single stack soil vent pipe (svp), terminal minimum 900 mm above window heads.
Bungalow only Vaulted roof	50 mm face pine boarding with clear varnish, or foil backed plasterboard with skim. 50 mm insulation battens between rafters giving 50 mm air gap. (Maximum U value 0.35 W/m^2 °C).
Detached house only a) stairs	13 equal risers to 2625 mm, 225 mm treads, maximum pitch 42°. Clear headroom to be minimum 2 m vertical, handrail height to be 840 mm above pitch line and 900 mm to landings. Maximum space between vertical ballusters 95 mm. Minimum clear width of stair and landings 800 mm.
b) upper floors	127 x19 mm tongue and groove floorboards on soft wood joists.

6.4 Material inputs to bungalow construction

Table 6.2 Material inputs to the construction of a three bedroom bungalow - 'as used' by builder (including a 5 % waste allowance on bulk items			
Materials	**Quantity**	**Units**	**Mass kg**
Minerals			
Limestone hardcore	31,920	kg	31,920
Quarry building sand	14,532	kg	14,532
Cement			
Bagged ordinary Portland cement	3,150	kg	3,150
Structural clay products			
65 mm facing and common brick	31,973	kg	31,973
100 mm diameter underground drainage pipes	31	m	408
Yard gulleys	6	units	63
Limestone products			
Block form mastic asphalt floor covering 15 mm deep	103	m^2	3,708
Concrete and mortar products			
Ready mixed concrete, 20 MPa - for footings/cavity fill	31,253	kg	31,253
Ready mixed concrete, 30 MPa - for floor	37,559	kg	37,559
Ready mixed cement:lime:sand mortar	5,250	kg	5,250
Concrete roof tiles	144	m^2	8,064
Concrete chimney flue set	2,400	kg	2,400
Dense concrete blocks - structural blockwork (440x215x100) mm	37.8	m^2	7,333
Aerated concrete blocks (440x215x140) mm	119	m^2	12,495
Pre-stressed concrete lintels (255x75) mm	2.75	m	125
Plaster/plasterboard			
Plaster - bagged	1,394	kg	1,394
Plasterboard 12.5 mm	230	m^2	2,070
Timber			
Floorboards/joists/rafters/studding - unseen (UK produce)	3,675	kg	3,675
Window frames, door frames and doors - seen (imported timber)	564	kg	564
Glazing			
Flat glass - 6 mm double glazing	8.3	m^2	124.5
Metals items			
Galvanised steel items: hangers, straps, angle beading	69	kg	69
Steel beams	175	kg	175
Galvanised pressed steel lintels	17.1	m	152
Leadwork	157.5	kg	157.5
Copper pipes and copper hot water cylinder - hot/cold water supply	27	kg	27
Plastic/polymeric items			
Polyethylene damproof membrane	24	kg	24
Polyethylene damproof course	25.8	m^2	13
PVC guttering/pipework	31.5	kg	31.5
Paintwork (solids)	22.7	kg	22.7
Insulation			
Fibreglass roof insulation, 150 mm	87	m^2	261
Total mass input (including 5 % waste on bulk items)			198,993
Less 5 % waste			-9,277
Mass of finished bungalow			189,716

6.5 Material inputs to detached house construction

Table 6.3 Material inputs to the construction of a four bedroom detached house - 'as used' by builder (including 5 % waste allowance on bulk items

Materials	Quantity	Units	Mass kg
Minerals			
Limestone hardcore	26,880	kg	26,880
Quarry building sand	15,120	kg	15,120
Cement			
Bagged ordinary Portland cement	4,200	kg	4,200
Structural clay products			
65 mm facing and common brick	40,163	kg	40,163
100 mm diameter underground drainage pipes	30	m	395
Yard gulleys	4	units	42
Limestone products			
Block form mastic asphalt floor covering 15 mm deep	49	m^2	1,764
Concrete and mortar products			
Ready mixed concrete, 20 MPa - for footings/cavity fill	36,015	kg	36,015
Ready mixed concrete, 30 MPa - for floor	30,870	kg	30,870
Ready mixed cement:lime:sand mortar	6,300	kg	6,300
Concrete roof tiles	110	m^2	6,160
Concrete chimney flue set	2,400	kg	2,400
Dense concrete blocks - structural blockwork (440x215x100) mm	34.6	m^2	6,712
Aerated concrete blocks (440x215x140) mm	227	m^2	27,013
Pre-stressed concrete lintels (255x75) mm	3.46	m	158
Plaster/plasterboard			
Plaster - bagged	3,271	kg	3,271
Plasterboard 12.5 mm	274	m^2	2,466
Timber			
Floorboards/joists/rafters/studding - unseen (UK produce)	3,961	kg	3,961
Window frames, door frames and doors - seen (imported timber)	895	kg	895
Glazing			
Flat glass - 6 mm double glazing	13.4	m^2	201
Metals items			
Galvanised steel items: hangers, straps, angle beading	122	kg	122
Steel beams	125	kg	125
Galvanised pressed steel lintels	25.1	m	262
Leadwork	105	kg	105
Copper pipes and copper hot water cylinder - hot/cold water supply	36	kg	36
Plastic/polymeric items			
Polyethylene damproof membrane	18	kg	18
Polyethylene damproof course	16.8	m^2	8.4
PVC guttering/pipework	59	kg	59
Paintwork (solids)	31.5	kg	31.5
Insulation			
Fibreglass roof insulation, 150 mm	61	m^2	183
Total mass input (including 5 % waste on bulk items)			215,936
Less 5 % waste			-10,069
Mass of finished house			**205,867**

Chapter 7

ECO-PROFILES OF BUILDING CONSTRUCTION

7.1 Introduction

In this chapter the gross inputs and outputs associated with the construction of the specified bungalow house and detached house will be examined and comparisons made between the two types of building.

A further objective is to consider the relative proportions of both individual and collective inputs and outputs and to highlight any of significance. Finally, for each building, the sensitivity of the eco-profiles to a change in the magnitude of significant material inputs will be assessed.

7.2 Gross inputs and outputs

The gross inputs and outputs associated with the construction of the bungalow and detached house are detailed in Appendix 87. In most cases the inputs and outputs associated with house construction are greater than those associated with the bungalow. This is perhaps to be expected since the mass of the house (205,867 kg) exceeds that of the bungalow (189,716 kg). However, if the data are expressed in terms of floor space area (see Appendices 88 and 89), then the reverse is generally true. Gross energy data are used in Figure 7.1 to illustrate this reversal and to prove that for the two buildings in question, per unit area of floor space, the construction of the two storey detached house produces a considerable saving in gross energy consumption compared to the single storey bungalow house.

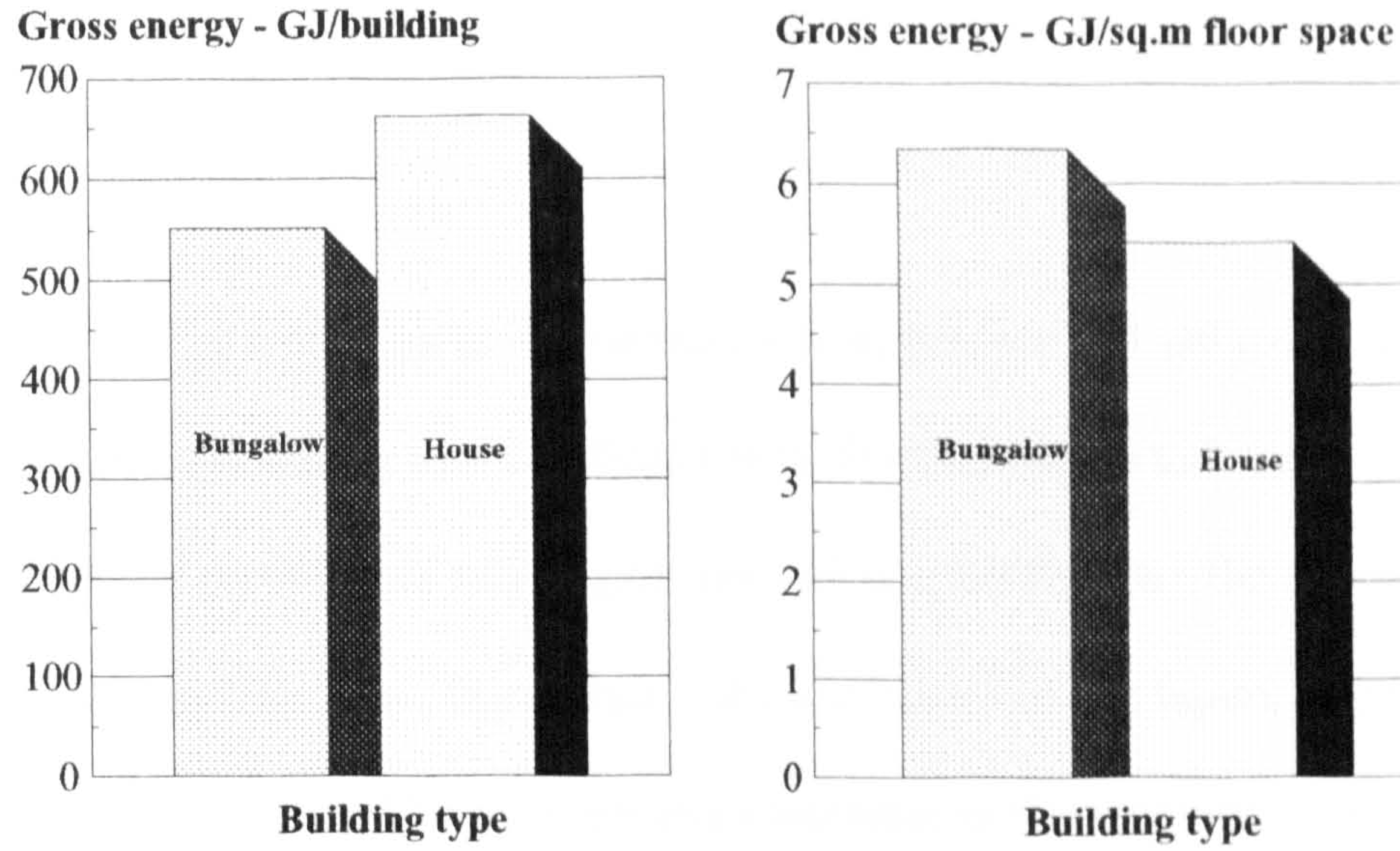


Figure 7.1 Gross construction energy for different building types

Table 7.1 A comparison of selected gross inputs and outputs to building construction

	per building			per m² floor space		
Input/Output	**Bungalow**	**House**	**% change**	**Bungalow**[1]	**House**[2]	**% change**
Gross inputs						
Energy (GJ)	552.30	662.52	19.96	6.35	5.42	-14.65
Raw materials (g)						
Sand	50,200,500	50,239,200	0.08	577,017	410,787	-28.81
Limestone	99,960,400	97,004,400	-2.96	1,149,000	793,168	-30.97
Clay	54,984,300	68,858,000	25.23	632,004	563,025	-10.91
Gross outputs (g)						
Air emissions						
Carbon dioxide	39,716,100	49,738,500	25.24	456,507	406,692	-10.91
Sulphur dioxide	312,146	403,472	29.26	3,588	3,299	-8.05
Water emissions						
Suspended solids	609,786	927,472	52.10	7,009	7,584	8.20

1 Floor area: 87.0 m²

2 Floor area: 122.3 m²

The gross inputs and outputs for the construction of the two buildings summarised in Table 7.1 indicate this saving to be 14.65 %. Similarly, reductions of 28.81 %, 30.97 % and 10.91 % are shown for raw material inputs of sand, limestone and clay respectively. Moreover, reductions of 10.91 % and 8.05 % are noted for carbon dioxide and sulphur dioxide emissions respectively. In contrast, and against the general trend, suspended solid discharges increase by 8.20 %.

For an explanation of these figures it is necessary to appreciate that reductions in the gross inputs and outputs per square metre of floor space, from bungalow to house, occur because the increases in the gross inputs and outputs per building are less than the corresponding 40.57 % increase in floor area. In contrast, values in excess of this figure, as observed for suspended solid discharges (52.10 %), generate increases in the gross inputs and outputs per square metre of floor space.

Such evidence suggests that for a given floor area an increase in building height may be synonomous with a decrease in environmental impact, and that further reductions in gross inputs and outputs may be possible in the construction of multi-storey buildings. Whilst this may be true for buildings constructed from the same materials and in roughly the same proportions, such as the bungalow and detached houses in this study, it is unsound and misleading to apply this principle to all buildings in all circumstances. In the case of multi-storey buildings, it is more than likely that the increase in load with height will be met by an increase in the use of high strength materials such as steel. Since steel has a high gross energy requirement and its production makes a significant environmental impact, the suggested reduction in gross inputs and outputs may not be realised.

It is interesting to note that the gross energy inputs given in Table 7.1 fall within the range of values reported by other workers as shown in Table 7.2. These figures will of course depend on the type of buildings, the choice of materials used, the accuracy of input data, material omissions, and the country of origin. It is against this background that comparisons should be made.

Table 7.2 Published values of gross energy inputs to building construction				
Building type	**Gross energy GJ/m²**	**Country**	**Year**	**Endnote reference**
Standard 3 bedroom semi-detached	1.93	U.K.	1972	6
Standard 3 bedroom semi-detached	3.97	U.K.	1974	8
Conventional house bungalow	1.60	U.K.	1975	12
Timber frame house bungalow	0.87	U.K.	1975	12
Low flat dwellings	3.02	U.K.	1975	12
High flat dwellings	2.29	U.K.	1975	12
3 storey Community college	7.59	U.S.A.	1975	14
Brick veneer dwelling	1.32	Australia	1975	19
2 storey houses - brick/block loadbearing walls	1.24 - 2.27	U.K.	1976	23
- loadbearing crosswalls & lightweight infills	1.21 - 1.83	U.K.	1976	23
4 storey block of flats - vertical brick/block	1.70 - 2.68	U.K.	1976	23
9 storey block of flats - reinforced concrete loadbearing structures	4.19 - 4.80	U.K.	1976	23
Terrace house	7.03	U.K.	1977	26
Mid-terrace house	7.25	U.K.	1978	28
Theoretical models	1.23 -7.41	U.S.A.	1983	35
Timber frame house	3.20	N. Zealand	1983	37
2 storey houses -Timber foundations & frame	2.21	Canada	1992	45
- Concrete foundation & clay brick veneer	4.12	Canada	1992	45
- Concrete foundation & aluminium sidings	3.30	Canada	1992	45
- Concrete foundations & concrete block wall	2.83	Canada	1992	45

Moreover, it should also be noted that with the exception of Marcea and Lau's[45] limited work on carbon dioxide emissions, little interest has been shown by these workers in extending this type of study beyond gross energy considerations into a fully developed eco-profile or life-cycle analysis. The present work, using a superior iterative calculation technique, is the first attempt to do so. It is this uniqueness and originality that set it apart from earlier studies.

At this point it is appropriate to examine in more detail the gross input and output data shown in Appendices 88 and 89. The following observations are noted.

- An increase in gross energy consumption is accompanied by an overall increase in waste production and raw material consumption. This is perhaps to be expected since gross energy consumption is a good indicator of human activitiy, which in this case involves the conversion of raw materials into finished buildings and the production of waste materials.
- The most significant raw material input is water which accounts for about 60 % of the total mass input. However, apart from a small quantity retained by concrete products during curing processes, most water is used as a coolant, a solvent, a medium for chemical reactions, an eluent, or simply lost through evaporation and not carried forward with the finished product or considered as a waste product. Other significant contributions include clay, limestone and sand which taken together account for about 36 % of the total mass input.
- Carbon dioxide is the most significant gaseous emission accounting for over 97 % of all air emissions. It is a known greenhouse gas and its importance arises from its global warming potential.
- Although solid waste is not to be considered as a basis for comparison, the proportions of total waste production attributed to solid waste for bungalow and detached house construction are 52.49 % and 50.20 % respectively.
- Emissions to water are small compared to air emissions. Suspended solids are the most significant discharge and account for about 99 % of all water emissions.
- There is an apparent mass imbalance between raw material inputs on the one hand and outputs of waste matter and finished buildings on the other. Possible explanations for this apparent breach of the Law of Conservation of Mass are:

a) raw materials such as water, compressed air and separated nitrogen are included in the raw material inventory, but not in the waste product inventory,

b) air emissions such as carbon dioxide, carbon monoxide, sulphur dioxide, and oxides of nitrogen are included in the air emissions inventory, but arise from the combustion of fuels which are not included in the raw material inventory. It should be noted, however, that although 73 % of carbon dioxide emissions are produced from fuel combustion, the remaining 27 % is produced from the thermochemical decomposition of limestone during cement and lime manufacture, and is therefore accounted for in the raw material inventory.

7.3 Sensitivity analysis of material inputs

In many instances a choice exists between alternative building materials serving the same function. For example, roof tiles made from clay or concrete, or window frames made from wood or PVC. It is useful, therefore, to consider the effect on the eco-profiles of each building of using different materials. To do this it is necessary, as a first step, to consider the relative contributions to the gross inputs and outputs made by the building materials specified in the builder's schedules given in Tables 6.2 and 6.3. Rather than examine all the gross inputs and outputs, it is sufficient for this exercise to study the gross energy inputs alone. It is immaterial whether these inputs are expressed *per building* or *per m^2 of floor area*, the % contributions remains the same. The results of these analyses are shown in Tables 7.3 and 7.4 and provide an opportunity to identify any dominant material inputs and to assess the sensitivity of the eco-profiles to a change in material input.

Table 7.3 Gross energy inputs to bungalow construction attributed to material inputs - per building				
Material inputs	**Gross energy /GJ**		**%**	
Minerals				
Limestone hardcore	5.17		0.94	
Quarry building sand	1.63		0.29	
		6.80		1.23
Cement				
Bagged ordinary Portland cement	22.38		4.05	
		22.38		4.05
Structural clay products				
65 mm facing and common brick	156.76		28.38	
100 mm diameter underground drainage pipes	2.56		0.46	
Clay gulleys	0.83		0.15	
		160.14		28.99
Limestone products				
Block form mastic asphalt floor covering 15 mm deep	31.80		5.76	
		31.80		5.76
Concrete and mortar products				
Ready mixed concrete, 20 MPa - for footings/cavity fill	23.37		4.23	
Ready mixed concrete, 30 MPa - for floor	33.20		6.01	
Ready mixed cement:lime:sand mortar	5.88		1.06	
Concrete roof tiles	19.49		3.53	
Concrete chimney flue set	3.84		0.69	
Dense concrete blocks - structural blockwork (440x215x100) mm	6.79		1.23	
Aerated concrete blocks (440x215x140) mm	57.37		10.39	
Pre-stressed concrete lintels (255x75) mm	0.26		0.05	
		150.20		27.19
Plaster/plasterboard				
Plaster - bagged	3.82		0.69	
Plasterboard 12.5 mm	12.66		2.29	
		16.48		2.98
Timber				
Floorboards/joists/rafters/studding - unseen (UK produce)	86.73		15.70	
Window frames, door frames and doors - seen (imported timber)	22.24		4.03	
		108.97		19.73
Glazing				
Flat glass - 6 mm double glazing	3.64		0.66	
		3.64		0.66
Metals items				
Galvanised steel items: hangers, straps, angle beading	2.51		0.45	
Steel beams	5.71		1.03	
Galvanised combined steel lintels	6.27		1.14	
Leadwork	8.03		1.45	
Copper pipes and copper hot water cylinder - hot/cold water supply	1.63		0.30	
		24.15		4.37
Plastic/polymeric items				
Polyethylene damproof membrane	2.42		0.44	
Polyethylene damproof course	1.31		0.24	
PVC guttering/pipework	2.37		0.43	
Paintwork (solids)	11.23		2.03	
		17.33		3.14
Insulation				
Fibreglass roof insulation, 150 mm	10.42		1.89	
		10.42		1.89
Totals		552.31		99.99

Table 7.4 Gross energy inputs to detached house construction attributed to material inputs - per building				
Material inputs	**Gross energy /GJ**		**%**	
Minerals				
Limestone hardcore	4.35		0.66	
Quarry building sand	1.70		0.26	
		6.05		0.92
Cement				
Bagged ordinary Portland cement	29.84		4.50	
		29.84		4.50
Structural clay products				
65 mm facing and common brick	196.91		29.72	
100 mm diameter undergroud drainage pipes	2.48		0.37	
Clay gulleys	0.55		0.08	
		199.94		30.17
Limestone products				
Block form mastic asphalt floor covering 15 mm deep	15.13		2.28	
		15.13		2.28
Concrete and mortar products				
Ready mixed concrete, 20 MPa - for footings/cavity fill	26.93		4.06	
Ready mixed concrete, 30 MPa - for floor	27.29		4.12	
Ready mixed cement:lime:sand mortar	7.06		1.07	
Concrete roof tiles	14.89		2.25	
Concrete chimney flue set	3.84		0.58	
Dense concrete blocks - structural blockwork (440x215x100) mm	6.22		0.94	
Aerated concrete blocks (440x215x140) mm	109.44		16.52	
Pre-stressed concrete lintels (255x75) mm	0.33		0.05	
		195.98		29.59
Plaster/plasterboard				
Plaster - bagged	8.96		1.35	
Plasterboard 12.5 mm	15.08		2.28	
		24.04		3.63
Timber				
Floorboards/joists/rafters/studding - unseen (UK produce)	93.48		14.11	
Window frames, door frames and doors - seen (imported timber)	35.29		5.33	
		128.77		19.44
Glazing				
Flat glass - 6 mm double glazing	5.91		0.89	
		5.91		0.89
Metals items				
Galvanised steel items: hangers, straps, angle beading	4.44		0.67	
Steel beams	4.08		0.62	
Galvanised combined steel lintels	10.83		1.64	
Leadwork	5.35		0.81	
Copper pipes and copper hot water cylinder - hot/cold water supply	2.17		0.33	
		26.87		4.07
Plastic/polymeric items				
Polyethylene damproof membrane	1.80		0.27	
Polyethylene damproof course	0.85		0.13	
PVC guttering/pipework	4.44		0.67	
Paintwork (solids)	15.59		2.35	
		22.68		3.42
Insulation				
Fibreglass roof insulation, 150 mm	7.31		1.10	
		7.31		1.10
Totals		662.52		100.01

It is clear from these results that the dominant material inputs belong to the *Structural clay products*, *Concrete and mortar products*, and *Timber* categories which collectively account for over 75 % of the total gross energy inputs. Within these categories unseen timber products, clay bricks and aerated concrete blocks make the largest contributions and it is here that the eco-profiles are most sensitive to change. However, few if any materials exist as practical alternatives to timber for these designated purposes. In contrast, both clay bricks and aerated concrete blocks compete with alternative materials such as dense concrete blocks and provide scope for variation and change.

Other material inputs, although essential to building construction, make a relatively minor contribution to the total gross energy. For many, such as sheet glass, cement and sand, no suitable alternatives are available. In contrast, some materials, such as wooden window frames and doors compete with PVC and aluminium alternatives. Although these materials may be relatively unimportant in terms of their contribution to the total gross energy of building construction, comparisons with competing alternatives are of interest and importance to producers.

In the next chapter alternative building materials will be compared and the effect of their substitution on the eco-profiles of buildings considered.

Chapter 8

A COMPARISON OF ALTERNATIVE BUILDING MATERIALS

8.1 Introduction

Before any comparisons between alternative building materials are made, it is important to re-state the key principle underpinning all life-cycle analysis that any such comparisons must be confined to systems performing identical functions. For example, when comparing PVC and wooden window frames, it is incorrect and meaningless to compare 1 kg of PVC with 1 kg of wood. Rather, it is the behaviour of the extended industrial systems producing PVC and wooden window frames that must be compared. Moreover, unlike the eco-profiles discussed throughout the present work, which omit the use or final disposal of products, in true life-cycle analyses comparisons between alternative building materials should be made over their complete life-cycles. Nonetheless, despite this limitation, where alternative building materials exist, the choice between them may be guided by comparing and contrasting the eco-profiles of their respective production systems, and by applying the principle that *least is best* to the gross inputs and outputs. In an ideal case, one production system will assert its superiority and select itself by virtue of much reduced gross inputs and outputs. However, in many cases the choice is not always clear as competing systems may each have advantageous claims to reduce one or more gross inputs or outputs. In comparing eco-profiles, the accuracy of the reported data should be borne in mind. Given that data are at best correct to within 5 or 10 %, see Section 2.6.4., the preferred production system should offer at least a 20 % reduction in gross inputs and outputs to claim any significant advantage.

Taking the above comments into consideration, the following groups of building materials, each serving equivalent functions, will now be compared. The effect of substituting alternative materials on the eco-profiles of the bungalow house and the two storey detached house will also be considered for those materials offering significant reductions in gross inputs and outputs.

- Roof tiles: clay and concrete
- Window frames/doors: timber, aluminium, PVC
- Sewer pipes/gullies: clay, PVC
- Roof drainage materials (drainpipes, gutters): aluminium, PVC
- Lintels: reinforced concrete, timber, steel, combined
- Building blocks: clay bricks, dense concrete blocks, aerated concrete blocks
- Insulation materials: glass fibre wool, expanded polystyrene (EPS), polyurethane

Detailed inventories of the gross inputs and outputs for the extended industrial systems producing these materials are contained in the Appendices. Rather than compare all inputs and outputs, selective comparisons will be made as established in Section 5.3. Using gross energy inputs, carbon dioxide and sulphur dioxide emissions, and suspended solid discharges as performance indicators, comparisons will be made by expressing one as a ratio of the other. Using this technique detailed comparisons between the above alternative materials are made in Sections 8.2 - 8.8 below.

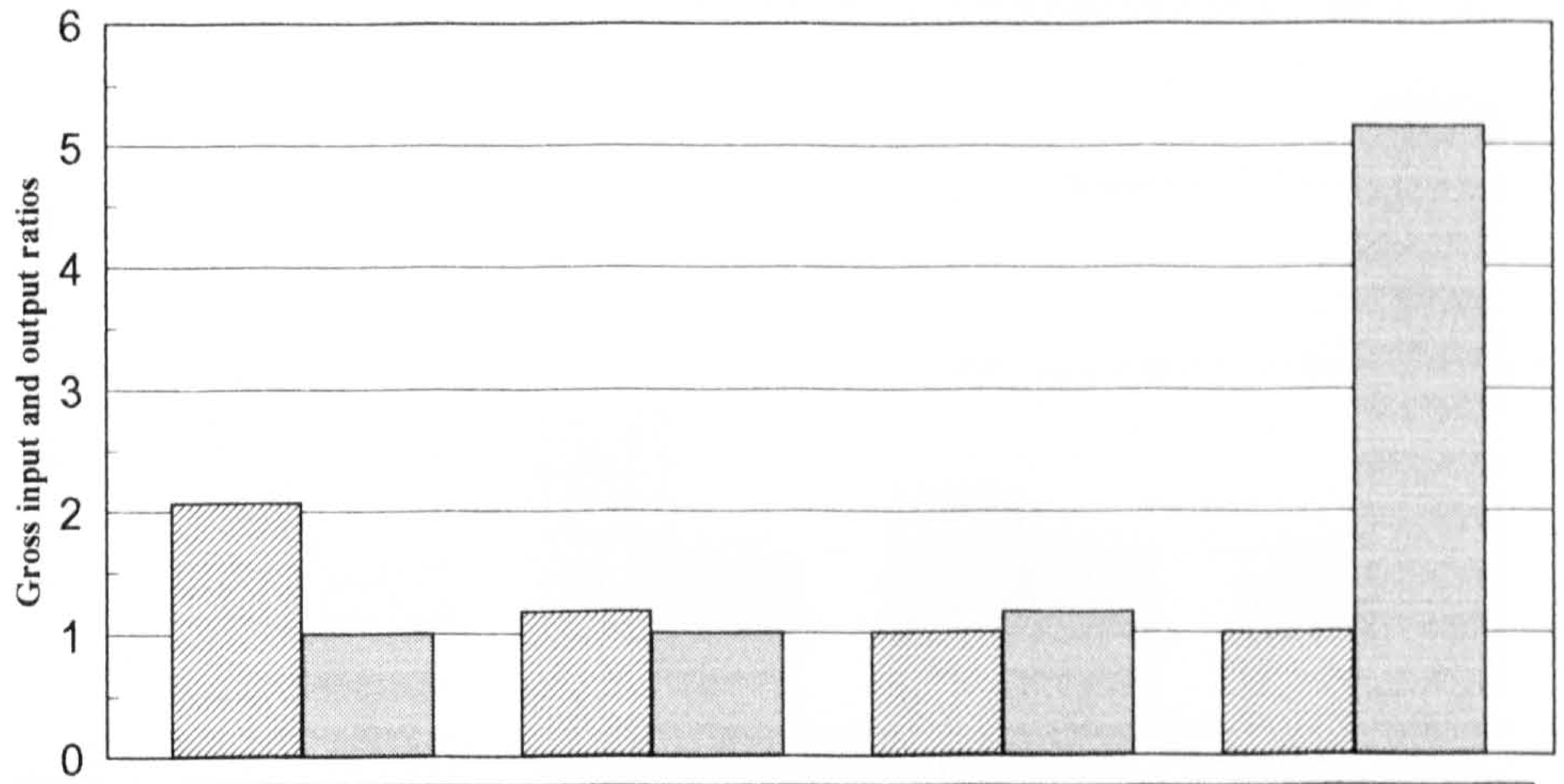
8.2 Roof tiles: *clay, concrete*

Clay and concrete are used as alternative materials in the construction of roof tiles. The selected gross inputs and outputs for the systems providing 1 square metre of roof cover from clay and concrete tiles are derived from Appendices 23 and 30 respectively.

These values are used to calculate comparative gross input and output ratios as shown in Table 8.1. The results of this exercise are depicted graphically in Figure 8.1.

Table 8.1 Selected gross inputs and outputs for systems producing roof tiles - per m^2								
Building material	**Gross energy**		**Air emissions**				**Water emissions**	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	**Ratio**	**mg**	**Ratio**	**mg**	**Ratio**	**mg**	**Ratio**
Clay	280.47	2.07	16,755,100	1.17	89,574	1.00	24,646	1.00
Concrete	135.34	1.00	14,329,800	1.00	104,088	1.16	126,953	5.15

Figure 8.1 Gross input and output ratios for systems producing roof tiles - per square metre



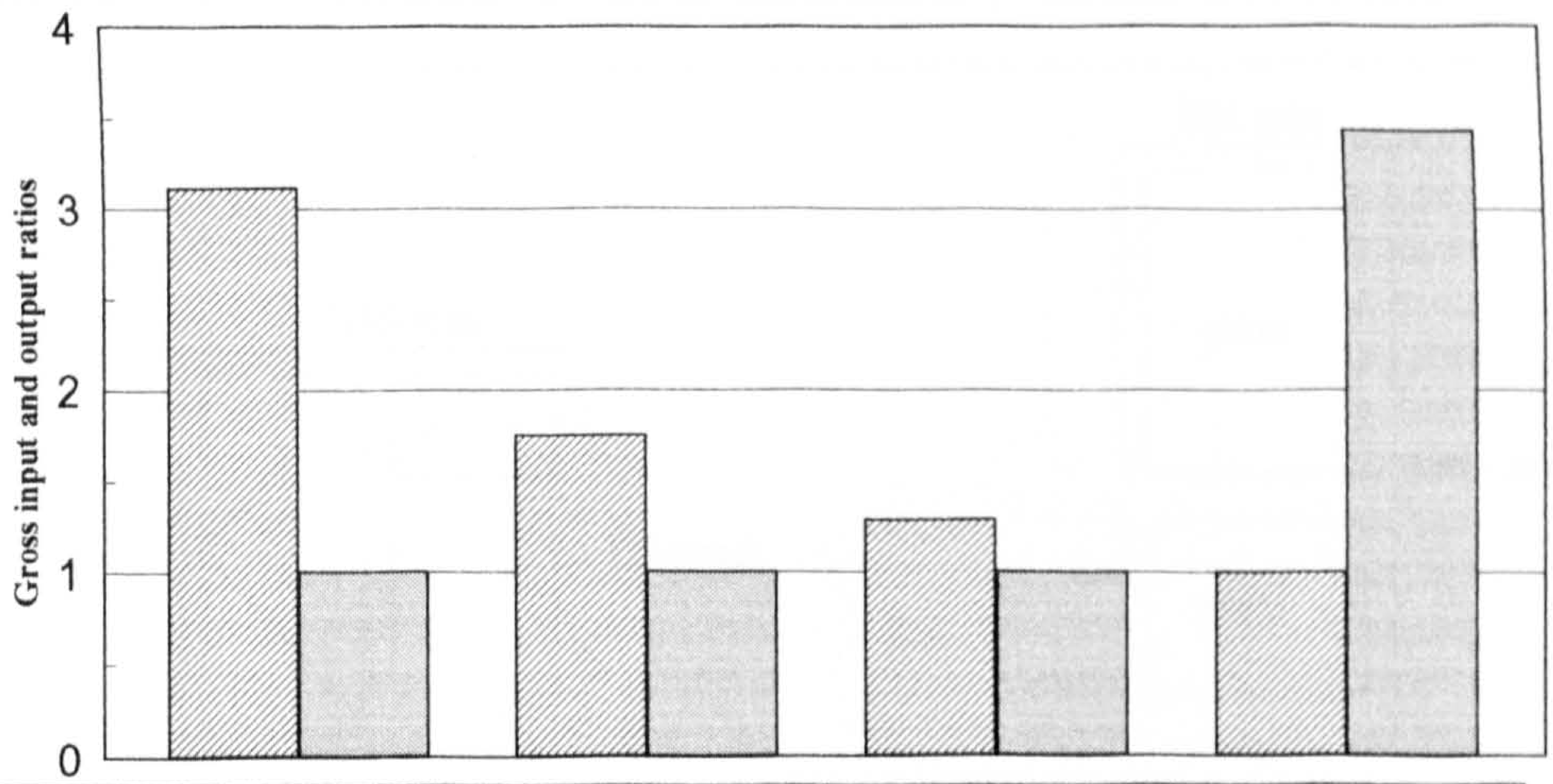
Roof tiles	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Clay	2.07	1.17	1.00	1.00
Concrete	1.00	1.00	1.16	5.15

From Figure 8.1 it can be seen that when judged in terms of gross energy and carbon dioxide inputs, the performance of the system producing concrete roof tiles is superior to that producing clay roof tiles, but inferior when sulphur dioxide and suspended solid emissions are compared. Clearly, both production systems offer advantages over the other. A more valid comparison can be made, however, by comparing the two systems over the expected lifetime of a modern house (70 years). Using the manufacturer's guaranteed lifetime for clay tiles (30 years) and concrete tiles (50 years), it is evident that three sets of clay tiles and two sets of concrete tiles will be required during this time. Table 8.2 shows modified gross input and output ratios calculated for the total number of tiles required during this period. The results of this comparison are shown graphically in Figure 8.2.

Table 8.2 Selected gross inputs and outputs for systems producing roof tiles during the lifetime of a house - per m²

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Clay	841.41	3.11	50,265,300	1.75	268,722	1.29	73,938	1.00
Concrete	270.68	1.00	28,659,600	1.00	208,176	1.00	253,906	3.43

Figure 8.2 Gross input and output ratios for systems producing roof tiles during the lifetime of a house - per square metre



Roof tiles	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Clay	3.11	1.75	1.29	1.00
Concrete	1.00	1.00	1.00	3.43

From Figure 8.2 it is evident that when judged over the expected lifetime of a modern house the performance of the system producing concrete roof tiles is enhanced compared to the system producing clay roof tiles. Moreover, the sulphur dioxide ratio is reversed to give an advantage to the concrete roof tile production system. Nonetheless, the performance of the clay roof tile system is superior when comparing suspended solid emissions. On balance, however, the system producing concrete roof tiles may be judged as the superior of the two systems and to offer distinct advantages, particularly for houses with long lifetimes. These conclusions are of particular interest given the absence of published data in this field.

8.3 Window frames/doors: *timber, aluminium, PVC*

Timber, PVC and aluminium are used extensively as alternative materials for the construction of window frames and doors. The gross inputs and outputs for window frame/door construction will clearly depend on the physical dimensions of the window or door opening. For the purposes of this comparison, two typical products will be considered as shown in Figure 8.3.

a) a two vent casement window frame - (1200 mm x 1200 mm)

b) an external kitchen door/frame - door dimensions (762 mm x 1981 mm)

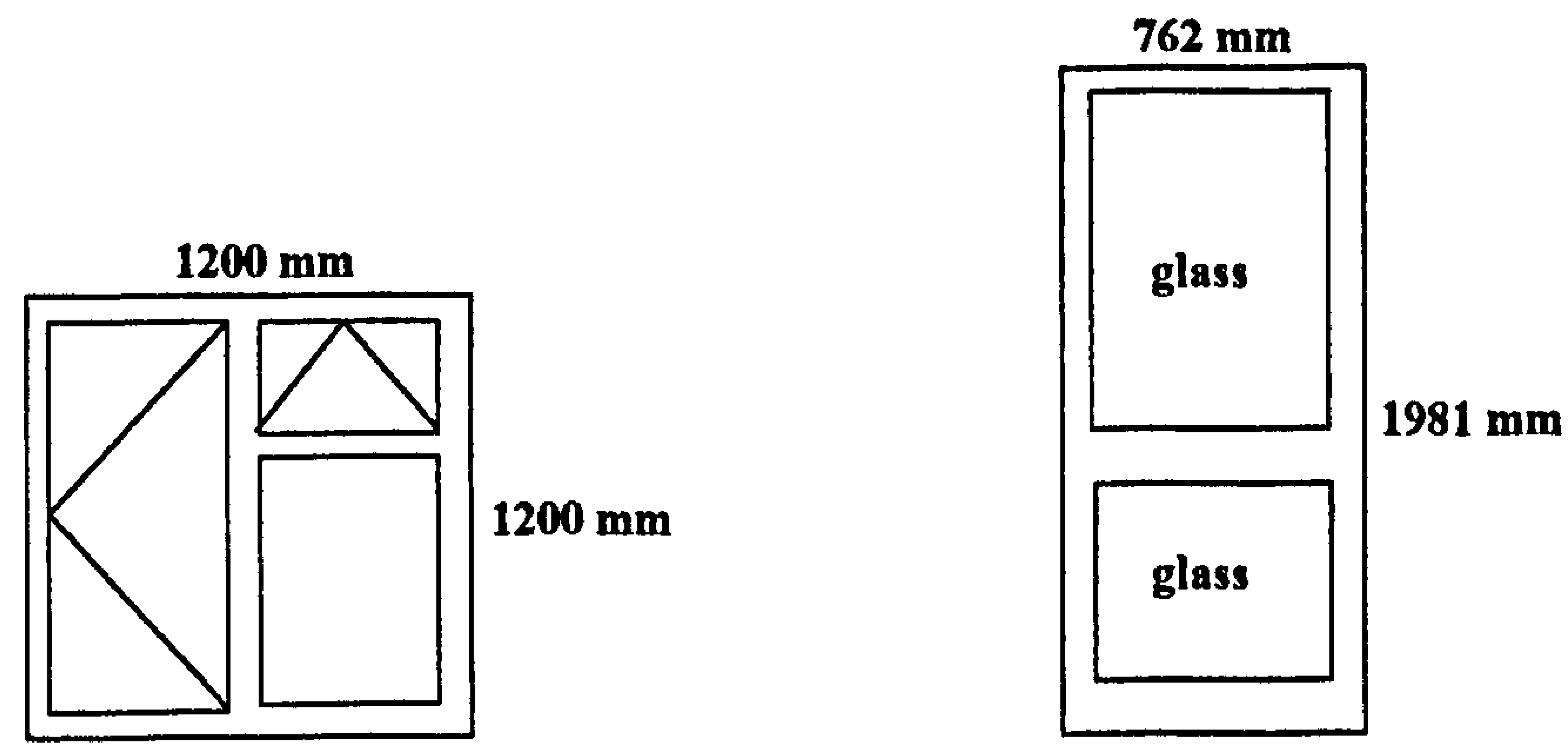
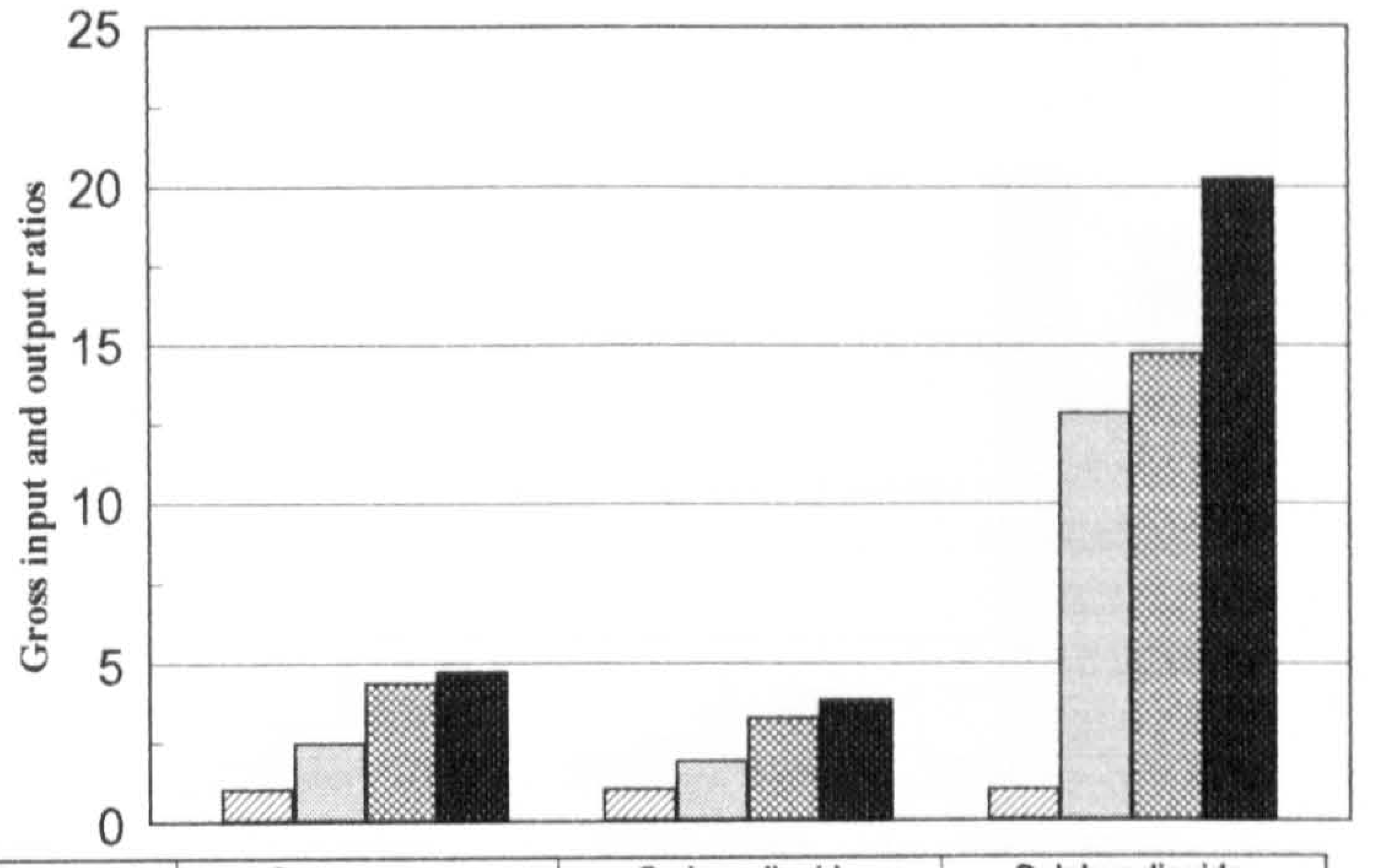


Figure 8.3 Diagram showing a) a two vent casement window
b) an external kitchen door

The gross input and output ratios for the systems producing the above casement window frame and the external kitchen door are derived from Appendices 48, 62, 63, 64, 65, 73, and 74. These ratios are given in Tables 8.3 and 8.4 respectively and graphically illustrated in Figures 8.4 - 8.5 and 8.6 - 8.7.

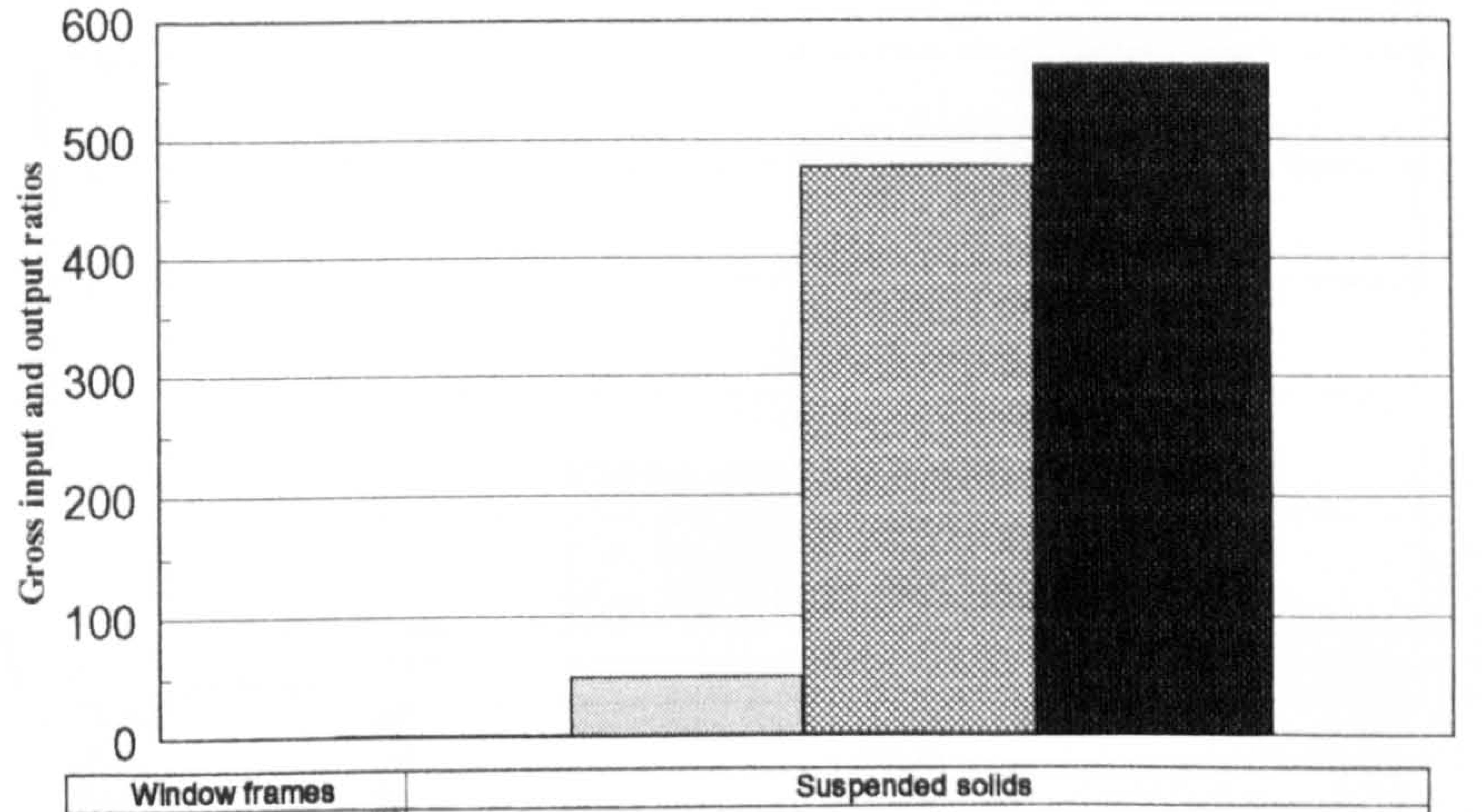
Table 8.3 Selected gross inputs and outputs for systems producing casement window frames (1200 mm x 1200 mm) - per frame								
Building material	**Gross energy**		**Air emissions**				**Water emissions**	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	**Ratio**	**mg**	**Ratio**	**mg**	**Ratio**	**mg**	**Ratio**
Timber	690.10	1.00	33,604,900	1.00	59,656	1.00	9,529	1.00
PVC	1,713.34	2.48	63,885,900	1.90	766,508	12.85	466,790	48.99
Aluminium (painted)	3,021.14	4.38	110,139,600	3.28	878,615	14.73	4,542,100	476.66
Aluminium (anodised)	3,261.14	4.73	128,761,200	3.83	1,206,000	20.22	5,354,000	561.86

Figure 8.4 Gross input and output ratios for systems producing casement window frames (1200 mm x 1200 mm) - per frame



Window frames	Gross energy	Carbon dioxide	Sulphur dioxide
Timber	1.00	1.00	1.00
PVC	2.48	1.90	12.85
Aluminium (painted)	4.38	3.28	14.73
Aluminium (anodised)	4.73	3.83	20.22

Figure 8.5 Gross input and output ratios for systems producing casement window frames (1200 mm x 1200 mm) - per frame

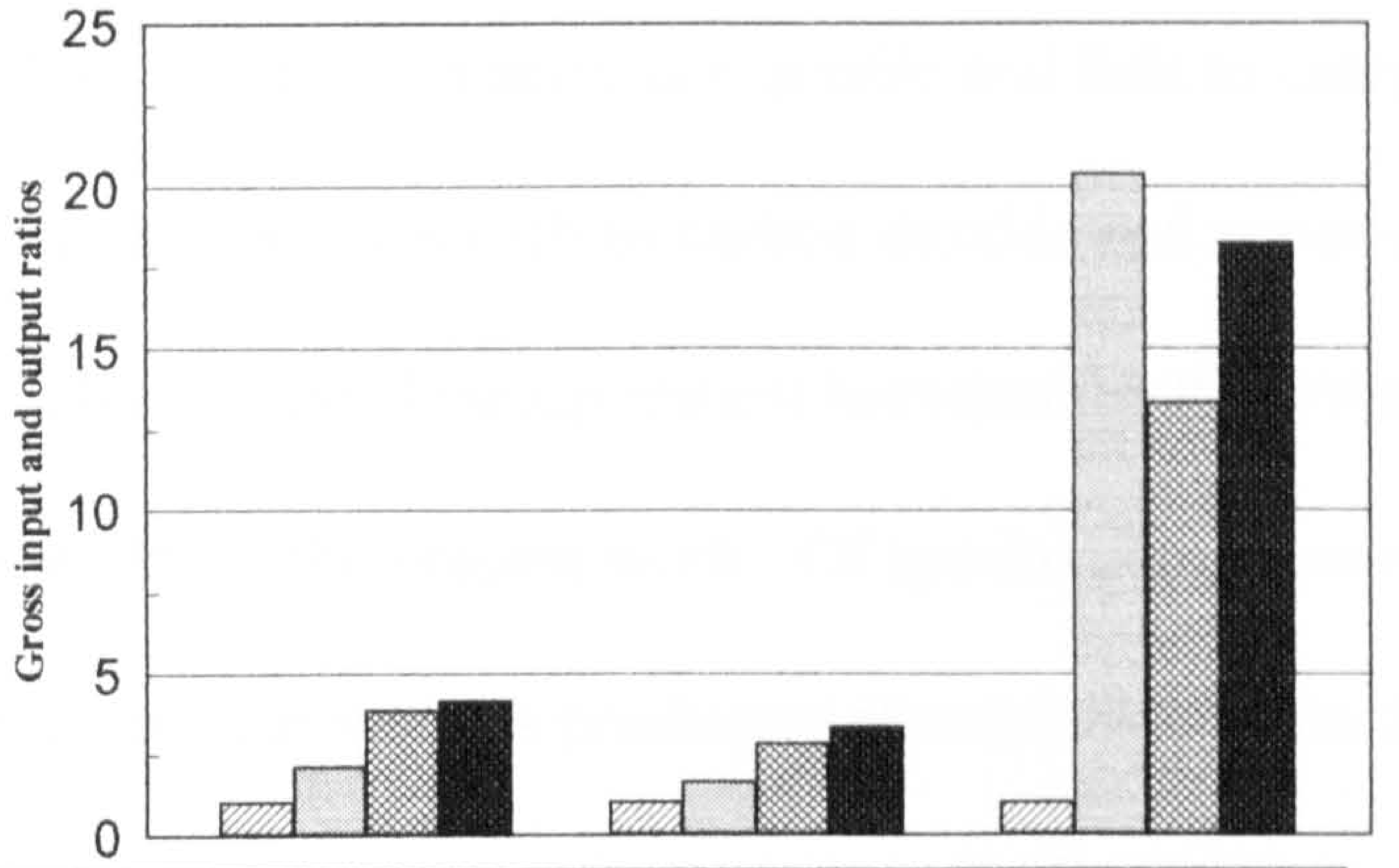


Window frames	Suspended solids
Timber	1.00
PVC	48.99
Aluminium (painted)	476.66
Aluminium (anodised)	561.86

Table 8.4 Selected gross inputs and outputs for systems producing external kitchen door & door frame: door size (762 mm x 1981 mm) - per door/doorframe

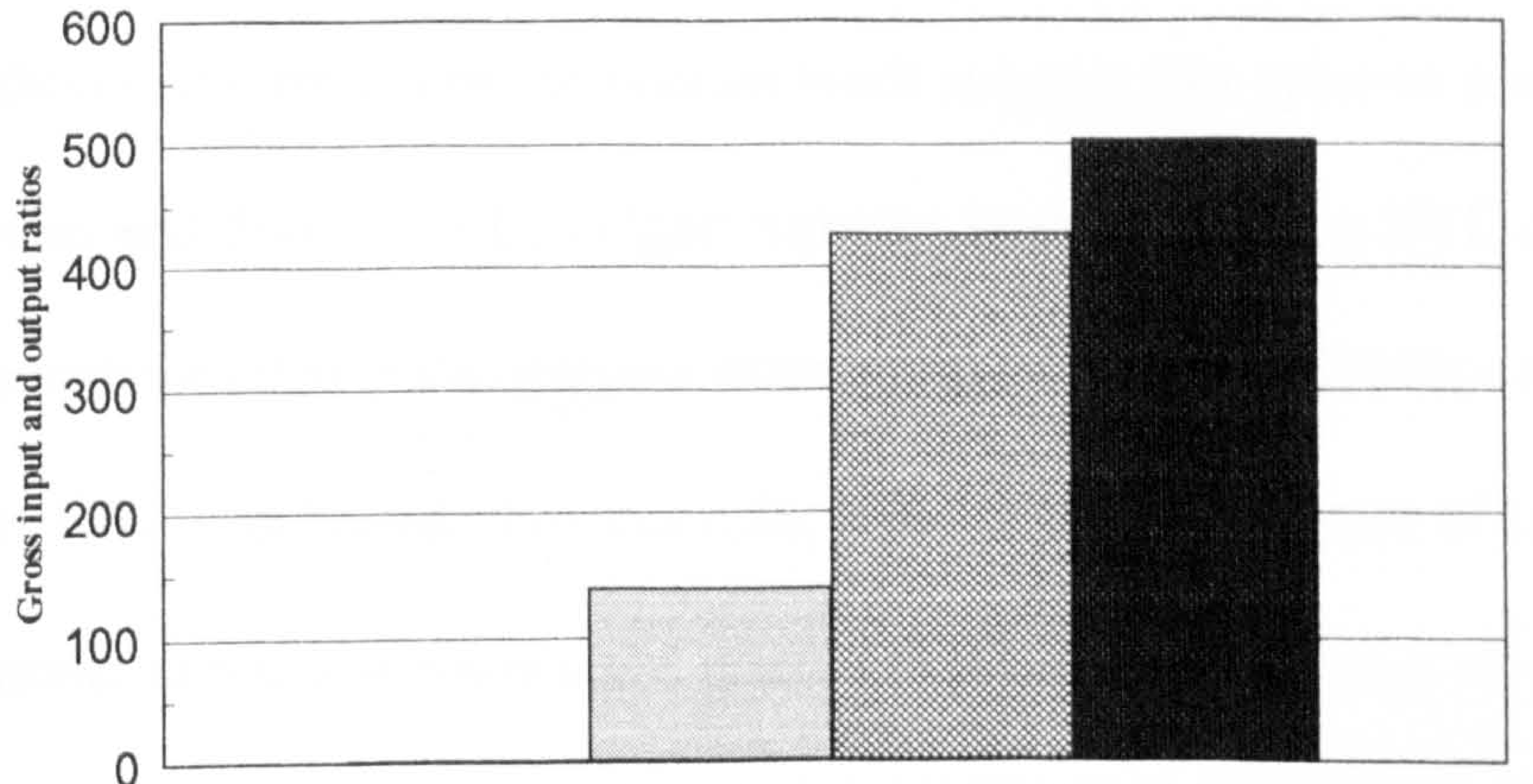
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Timber	1,214.57	1.00	59,144,600	1.00	104,995	1.00	16,771	1.00
PVC	2,581.05	2.12	97,607,300	1.65	2,142,900	20.41	2,329,800	138.92
Aluminium (painted)	4,666.63	3.84	167,983,900	2.84	1,399,200	13.33	7,158,600	426.84
Aluminium (anodised)	5,043.34	4.15	197,212,800	3.33	1,913,000	18.22	8,432,900	502.83

Figure 8.6 Gross input and output ratios for systems producing external kitchen door/frames: door size (762 mm x 1981 mm) - per door/frame



Door/frames	Gross energy	Carbon dioxide	Sulphur dioxide
Timber	1.00	1.00	1.00
PVC	2.12	1.65	20.41
Aluminium (painted)	3.84	2.84	13.33
Aluminium (anodised)	4.15	3.33	18.22

Figure 8.7 Gross input and output ratios for systems producing external kitchen door/frames: door size (762 mm x 1981 mm) - per door/frame



Door/frames	Suspended solids
Timber	1.00
PVC	138.92
Aluminium (painted)	426.84
Aluminium (anodised)	502.83

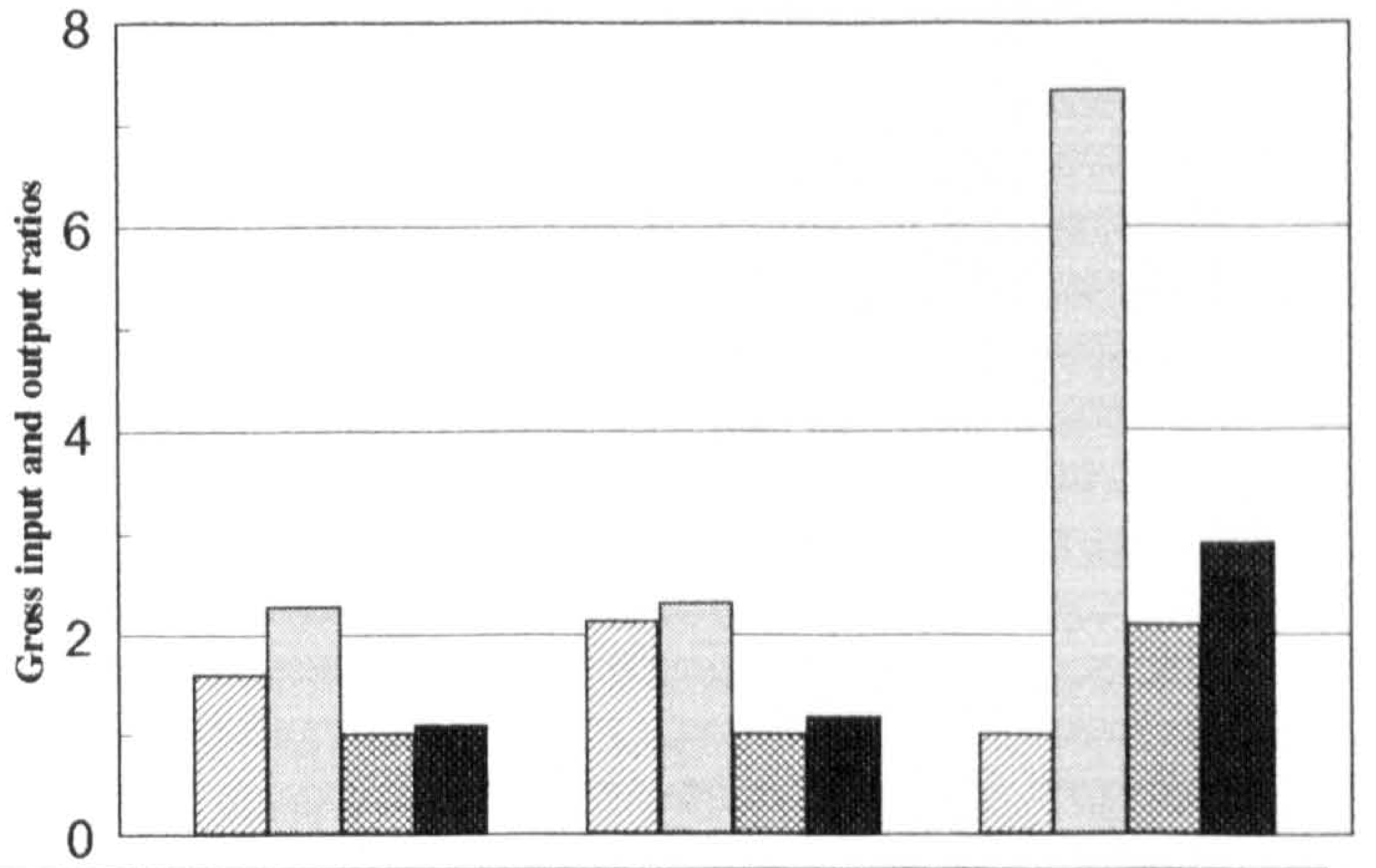
Using the gross input and output ratios as performance indicators, it is apparent from Figures 8.4 - 8.7 that systems using timber consistently outperform the others. When placed in increasing order of superiority the four systems in this study may be judged to read, *aluminium (anodised)*, *aluminium (painted)*, *PVC* and *timber*. This order is in line with Austrian research (1991)[44] which reaches similar general conclusions. However, despite any similarities with the present work, the Austrian study is limited to a discussion of gross energies, air emissions and solid waste production. It is neither a complete life-cycle analysis nor an exhaustive eco-profile and fails to categorise solid waste, or to include specific air emissions such as carbon dioxide and water emissions. Nonetheless, it is interesting to observe the close agreement between the PVC/timber gross energy ratio of 2.07 and the results of the present work. Of special note, however, is the improved performance quoted for systems producing aluminium window frames. For example, the aluminium/timber gross energy ratio is given as 2.62. This improvement may reflect differences in fuel production efficiencies and in the mix of primary fuels used for electricity generation.

Although the results of the present work suggest that systems producing timber window frames and doors may be judged superior to systems using PVC or aluminium, it must be remembered that if the systems were compared over the lifetime of a house the conclusions may well be different. For example, if the expected lifetimes of softwood, PVC and aluminium window frames and doors are taken as 10, 20 and 70 years respectively, the number of frame/door changes required during the expected lifetime of a modern house (70 years) are 7,4 and 1 respectively. Modified gross input and output ratios that take account of these different life expectancies are shown in Tables 8.5 - 8.6 and graphically illustrated in Figures 8.8 - 8.11.

Table 8.5 Selected gross inputs and outputs for systems producing casement window frames (1200 mm x 1200 mm) during the lifetime of a house - per frame

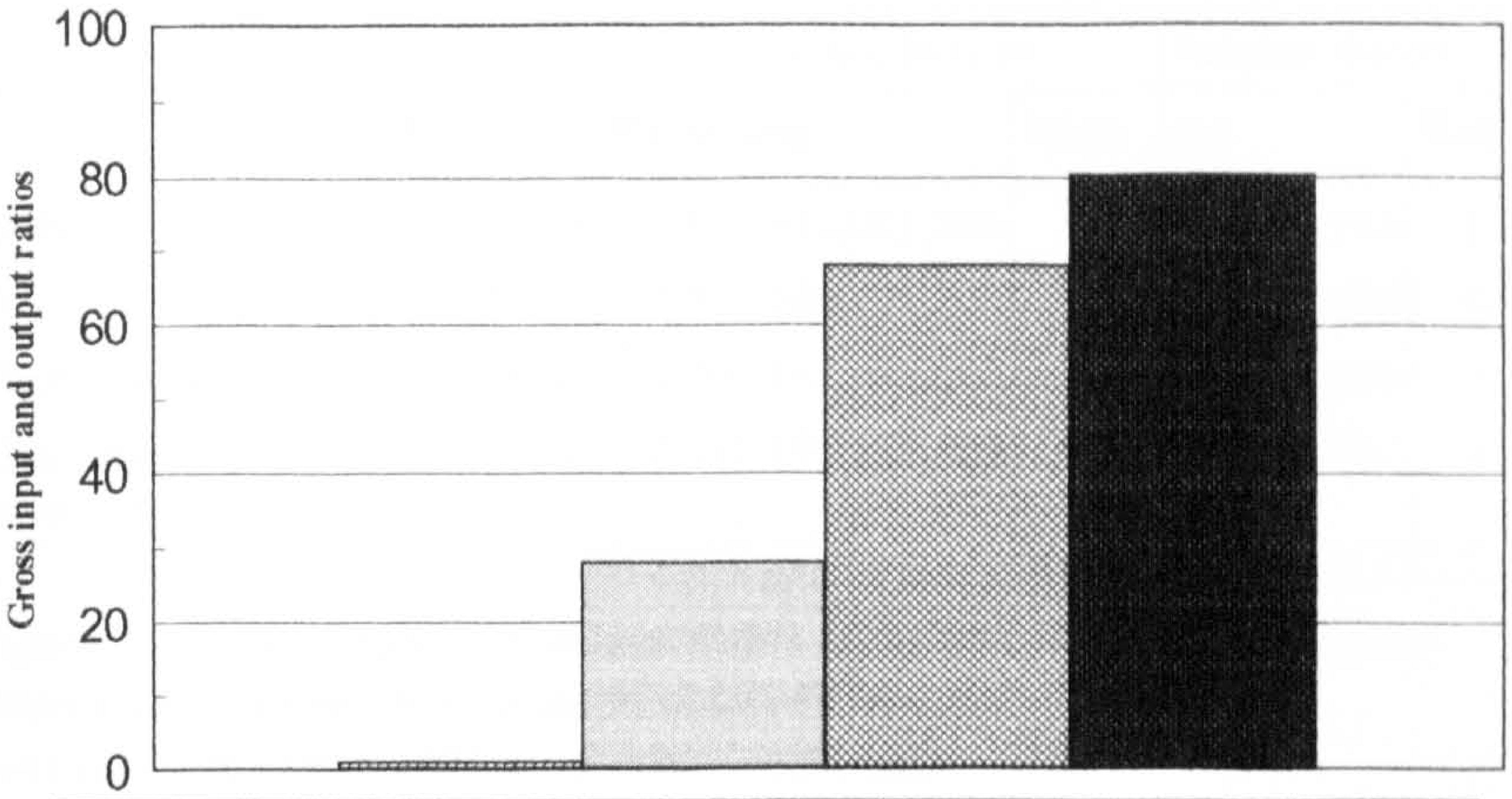
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Timber	4,830.70	1.60	235,234,300	2.14	417,592	1.00	66,703	1.00
PVC	6,853.36	2.27	255,543,600	2.32	3,066,032	7.34	1,867,160	27.99
Aluminium (painted)	3,021.14	1.00	110,139,600	1.00	878,615	2.10	4,542,100	68.09
Aluminium (anodised)	3,261.14	1.08	128,761,200	1.17	1,206,000	2.89	5,354,000	80.27

Figure 8.8 Gross input and output ratios for systems producing casement window frames (1200 mm x 1200 mm) during the lifetime of a house - per frame



Window frames	Gross energy	Carbon dioxide	Sulphur dioxide
Timber	1.60	2.14	1.00
PVC	2.27	2.32	7.34
Aluminium (painted)	1.00	1.00	2.10
Aluminium (anodised)	1.08	1.17	2.89

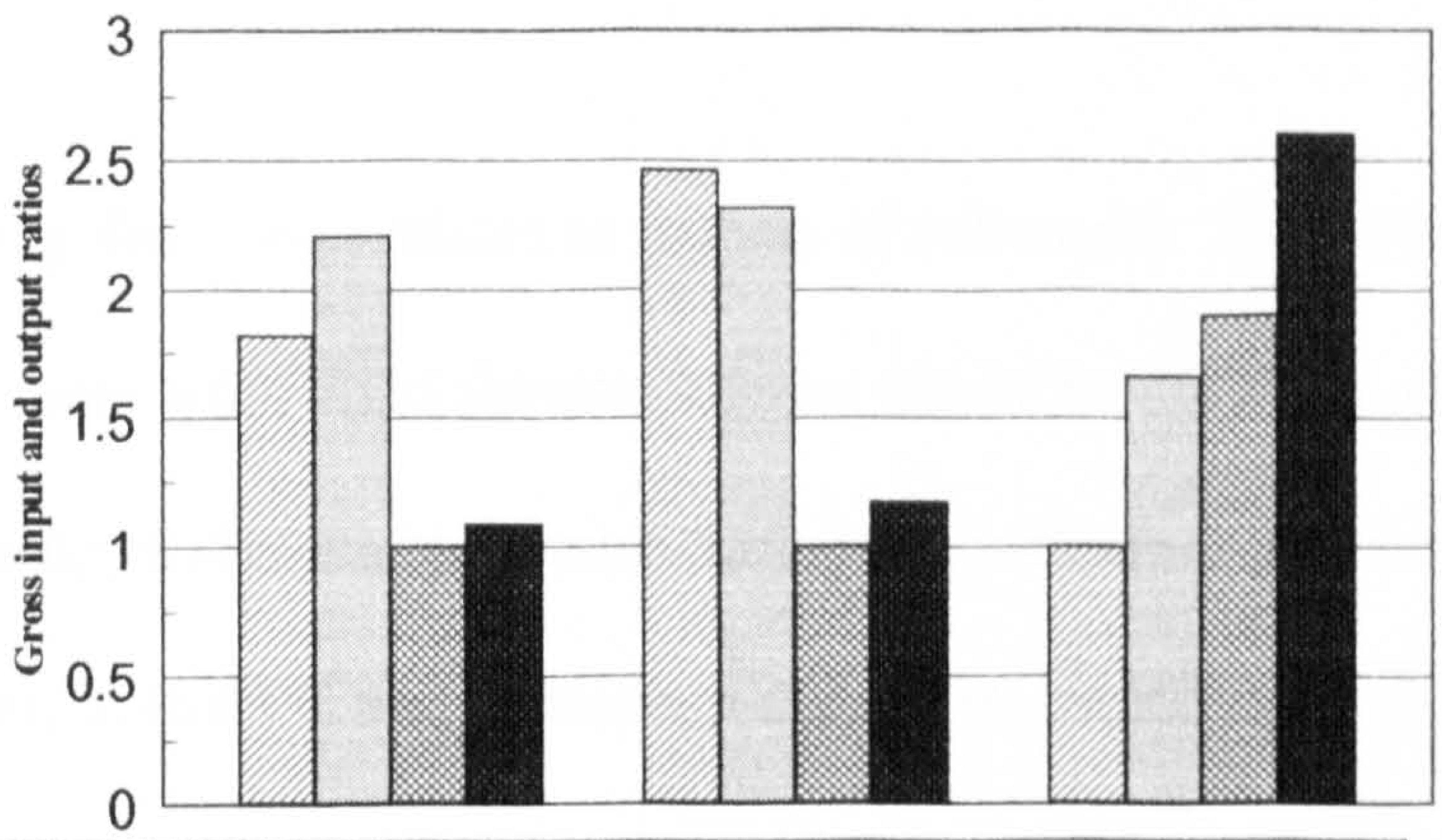
Figure 8.9 Gross input and output ratios for systems producing casement window frames (1200 mm x 1200 mm) during the lifetime of a house - per frame



Window frames	Suspended solids
Timber	1.00
PVC	27.99
Aluminium (painted)	68.09
Aluminium (anodised)	80.27

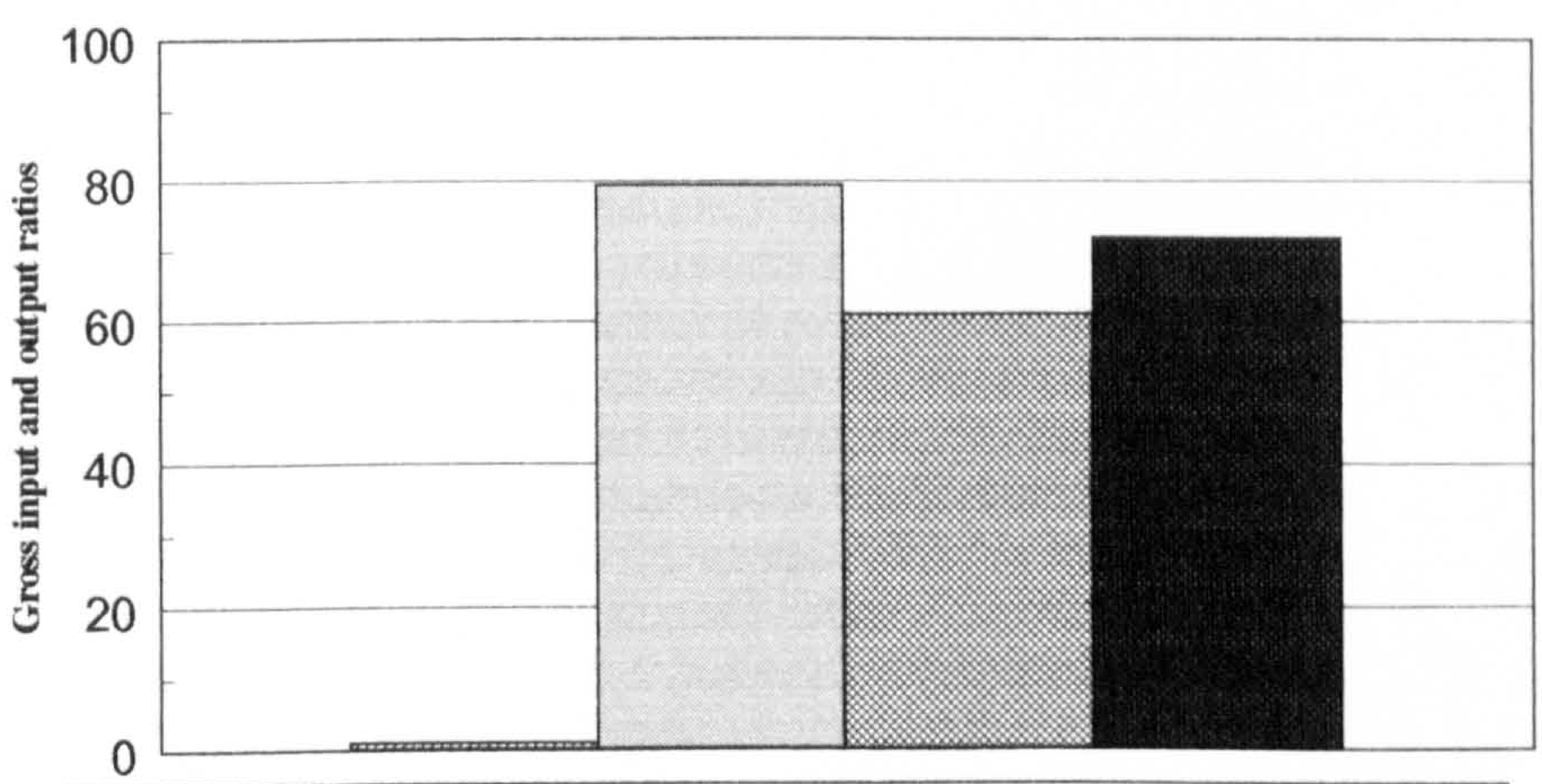
Table 8.6 Selected gross inputs and outputs for systems producing external kitchen door & door frames: door size (762 mm x 1981 mm) during the lifetime of a house - per door/door frame								
Building material	**Gross energy**		**Air emissions**				**Water emissions**	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	**Ratio**	**mg**	**Ratio**	**mg**	**Ratio**	**mg**	**Ratio**
Timber	8,501.99	1.82	414,012,200	2.46	734,965	1.00	117,397	1.00
PVC	10,324.20	2.21	390,429,200	2.32	8,571,600	1.66	9,319,200	79.38
Aluminium (painted)	4,666.63	1.00	167,983,900	1.00	1,399,200	1.90	7,158,600	60.98
Aluminium (anodised)	5,043.34	1.08	197,212,800	1.17	1,913,000	2.60	8,432,900	71.83

Figure 8.10 Gross input and output ratios for systems producing external kitchen door/frames during the lifetime of a house: door size: (762 mm x 1981 mm) - per door/frame



Door/frames	Gross energy	Carbon dioxide	Sulphur dioxide
Timber	1.82	2.46	1.00
PVC	2.21	2.32	1.66
Aluminium (painted)	1.00	1.00	1.90
Aluminium (anodised)	1.08	1.17	2.60

Figure 8.11 Gross input and output ratios for systems producing external kitchen door/frames during the lifetime of a house: door size (762 mm x 1981 mm) - per door/frame



Door/frames	Suspended solids
Timber	1.00
PVC	79.38
Aluminium (painted)	60.98
Aluminium (anodised)	71.83

The noticeable feature of these results is that unlike the earlier results illustrated in Figures 8.4 - 8.7, no one system displays an outright overall advantage. Although the performance of the systems producing aluminium frames and doors are superior when measured in terms of gross energy inputs and carbon dioxide emissions, the systems producing softwood frames and doors retain an advantage when judged in terms of sulphur dioxide and suspended solid emissions. It is interesting to observe that the systems producing PVC frames and doors are consistently outperformed by the other two.

The preceding discussion relates to the use of softwood. If hardwood, with a longer life expectation, was substituted the conclusions would be different. Similarly, if a full life-cycle analysis was applied to these systems different conclusions may be reached. For example, unlike timber, both PVC and aluminium may be re-cycled. Moreover, timber products require regular and frequent maintenance throughout their lifetime, making use of chemical preservatives, paints and varnishes.

8.4 Underground sewer pipes and gullies: *vitrified clay, PVC*

Vitrified clay and PVC compete with each other as alternative materials used to manufacture underground sewerage systems. According to previous studies by Boustead & Hancock,[32, 36] systems producing vitrified clay pipes outperform equivalent PVC systems. Although these studies focus exclusively on gross energy requirements, they provide a starting point for comparisons in the present study. However, unlike the preceding studies, this analysis is not an exhaustive study of all the variously sized pipes, junctions and bends used to construct complete sewerage systems. Instead, it is restricted to two items commonly used in house construction:

a) 100 mm (int. diameter) pipes per metre run *(based on data for 1.6 m clay pipes and 4 m PVC pipes)*

b) yard (bottle) gullies - (195 mm x 335 mm)

The gross input and output ratios for the systems producing the above pipes and gullies are derived from Appendices 24, 25, 77, and 78. These ratios are given in Tables 8.7 and 8.8 respectively and represented graphically in Figures 8.12 and 8.13.

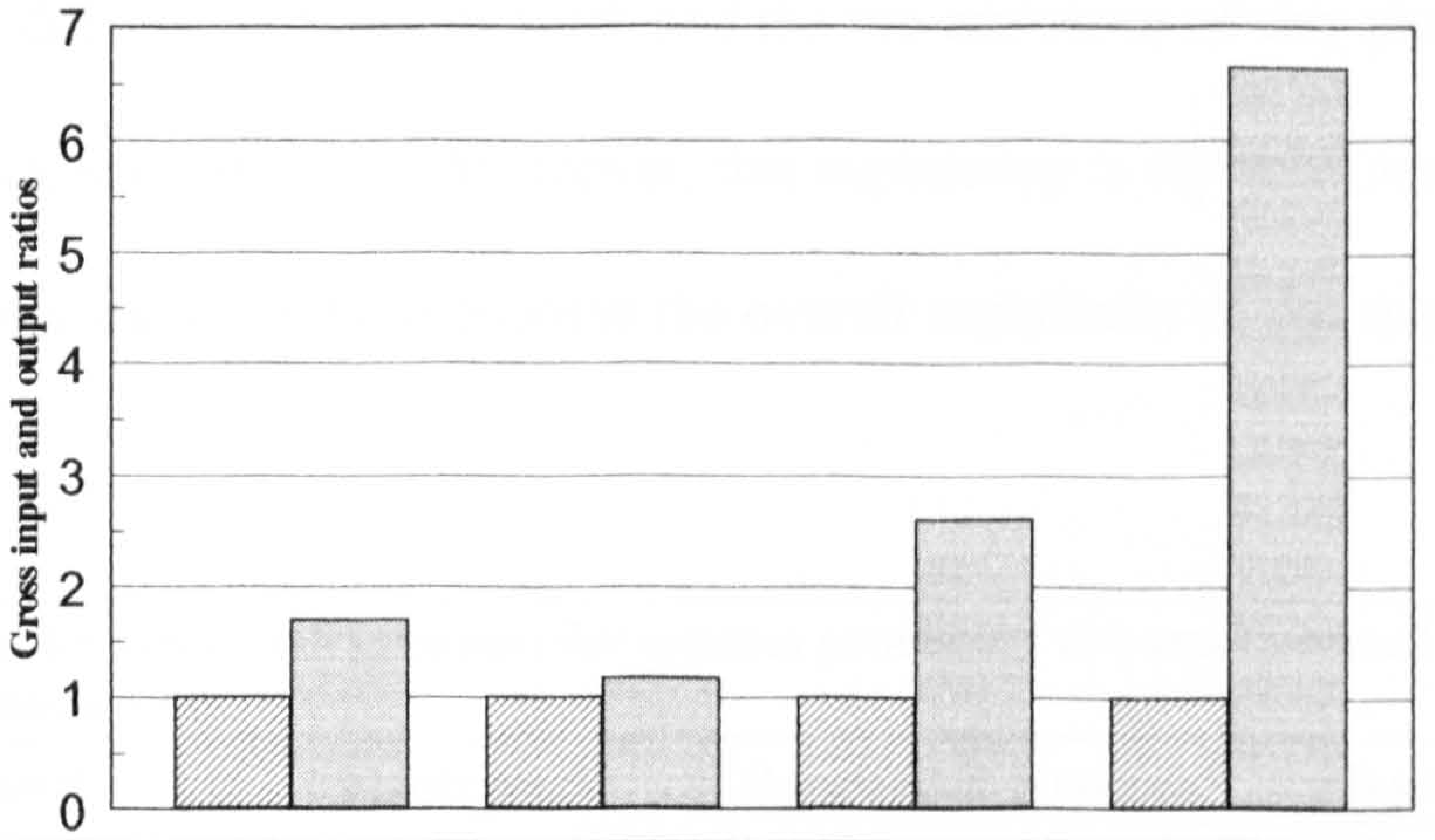
Table 8.7 Selected gross inputs and outputs for systems producing 100 mm (internal diameter) underground sewer pipes - per metre run

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Vitrified clay	82.64	1.00	4,261,700	1.00	18,809	1.00	3,614	1.00
PVC	140.43	1.70	4,984,600	1.17	48,886	2.60	23,994	6.64

Table 8.8 Selected gross inputs and outputs for systems producing yard gullies - per gulley

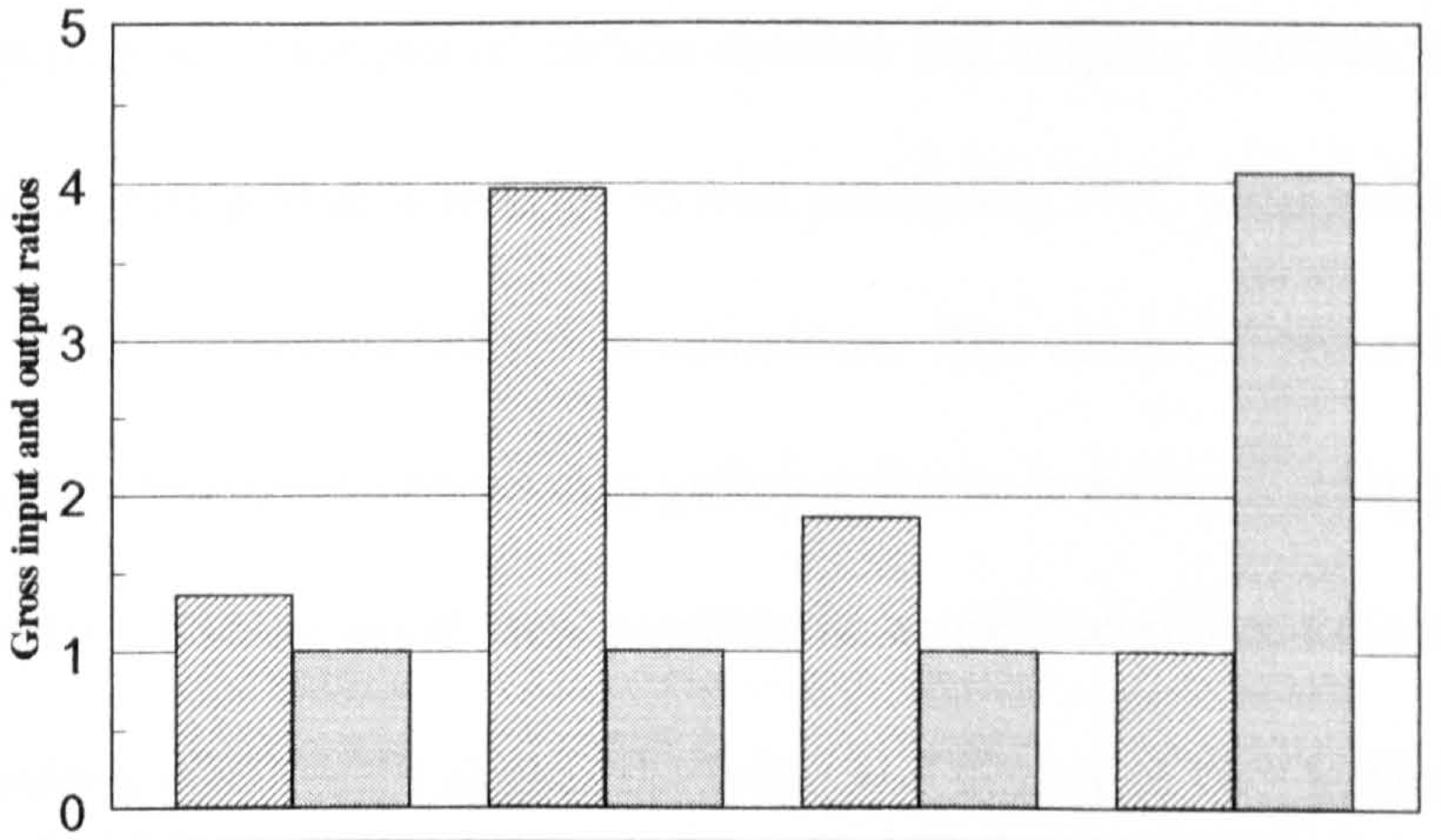
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Vitrified clay	137.83	1.36	13,615,900	3.97	61,135	1.86	3,280	1.00
PVC	101.13	1.00	3,434,000	1.00	32,842	1.00	13,314	4.06

Figure 8.12 Gross input and output ratios for systems producing 100 mm (internal diameter) sewer pipes - per metre run



Sewer pipes	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Vitrified clay	1.00	1.00	1.00	1.00
PVC	1.70	1.17	2.60	6.64

Figure 8.13 Gross input and output ratios for systems producing yard gullies - per gulley



Yard gullies	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Vitrified clay	1.36	3.97	1.86	1.00
PVC	1.00	1.00	1.00	4.06

When judged in terms of gross energy requirements, the results of this exercise confirm Boustead & Hancock's earlier work and the pre-eminence of clay pipes over PVC equivalents; see Table 8.9. Moreover, this supremacy is repeated across the remaining gross inputs and outputs to endorse the overall superiority of the system producing clay pipes.

Table 8.9 Gross energy inputs for systems producing 100 mm (internal diameter) pipes - per metre run						
Material	**Present work**		**Boustead & Hancock[32]**		**Boustead & Hancock[36]**	
	Gross energy MJ	**Ratio**	**Gross energy MJ**	**Ratio**	**Gross energy MJ**	**Ratio**
Vitrified clay	82.64	1.00	98.49	1.00	78	1.00
PVC	140.43	1.70	152.00	1.54	175	2.24

However, the advantageous position of clay is challenged when the systems producing yard gullies are examined. From Figure 8.13 it is evident that when measured in terms of gross energy inputs and emissions of carbon dioxide and sulphur dioxide, the system producing vitrified clay yard gullies is inferior to that producing PVC yard gullies but superior when judged in terms of suspended solids emissions. The observed reversal for gross energy inputs and air emissions, places clay gulley systems in a disadvantaged position compared to PVC systems. This reversal may possibly be attributed to the following factors:

a) low stacking efficiencies during the firing and drying of clay gullies

b) the use of a less efficient intermittent kiln (c.f. the use of a continuous kiln for pipes).

More convincing conclusions may be drawn, however, by measuring the gross inputs and outputs of replacement pipes and gullies during the 70 year expected lifetime of a modern house. Taking the manufacturers guaranteed lifetimes of clay and PVC pipes and gullies as 100 years and 50 years respectively, revised gross inputs and output ratios may be calculated. The results are shown in Tables 8.10 and 8.11 and graphically illustrated in Figures 8.14 and 8.15.

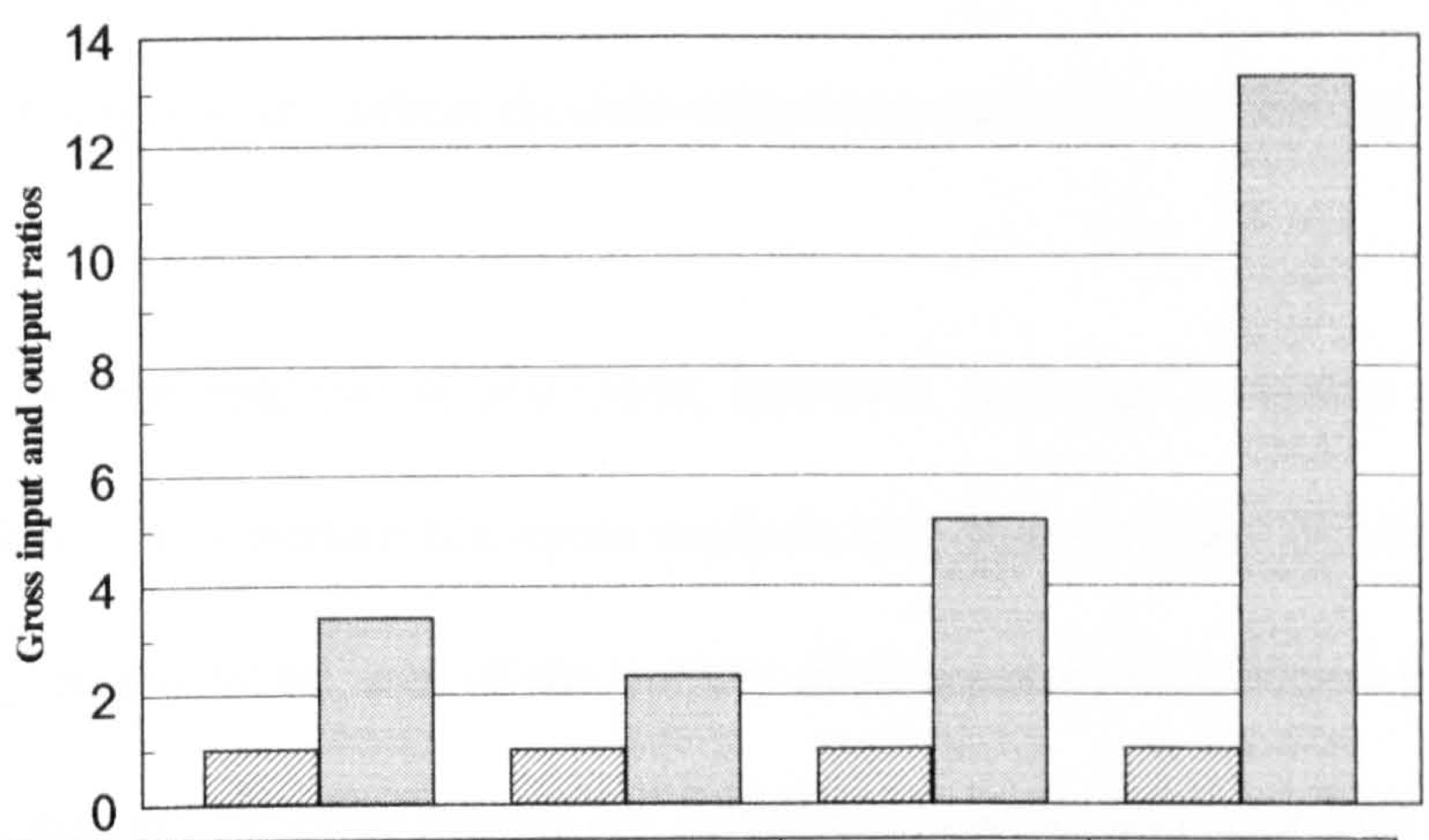
Table 8.10 Selected gross inputs and outputs for systems producing 100 mm (internal diameter) underground sewer pipes during the lifetime of a house - per metre run

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Vitrified clay	82.64	1.00	4,261,700	1.00	18,809	1.00	3,614	1.00
PVC	280.86	3.40	9,969,200	2.34	97,772	5.20	47,988	13.28

Table 8.11 Selected gross inputs and outputs for systems producing yard gullies during the lifetime of a house - per gulley

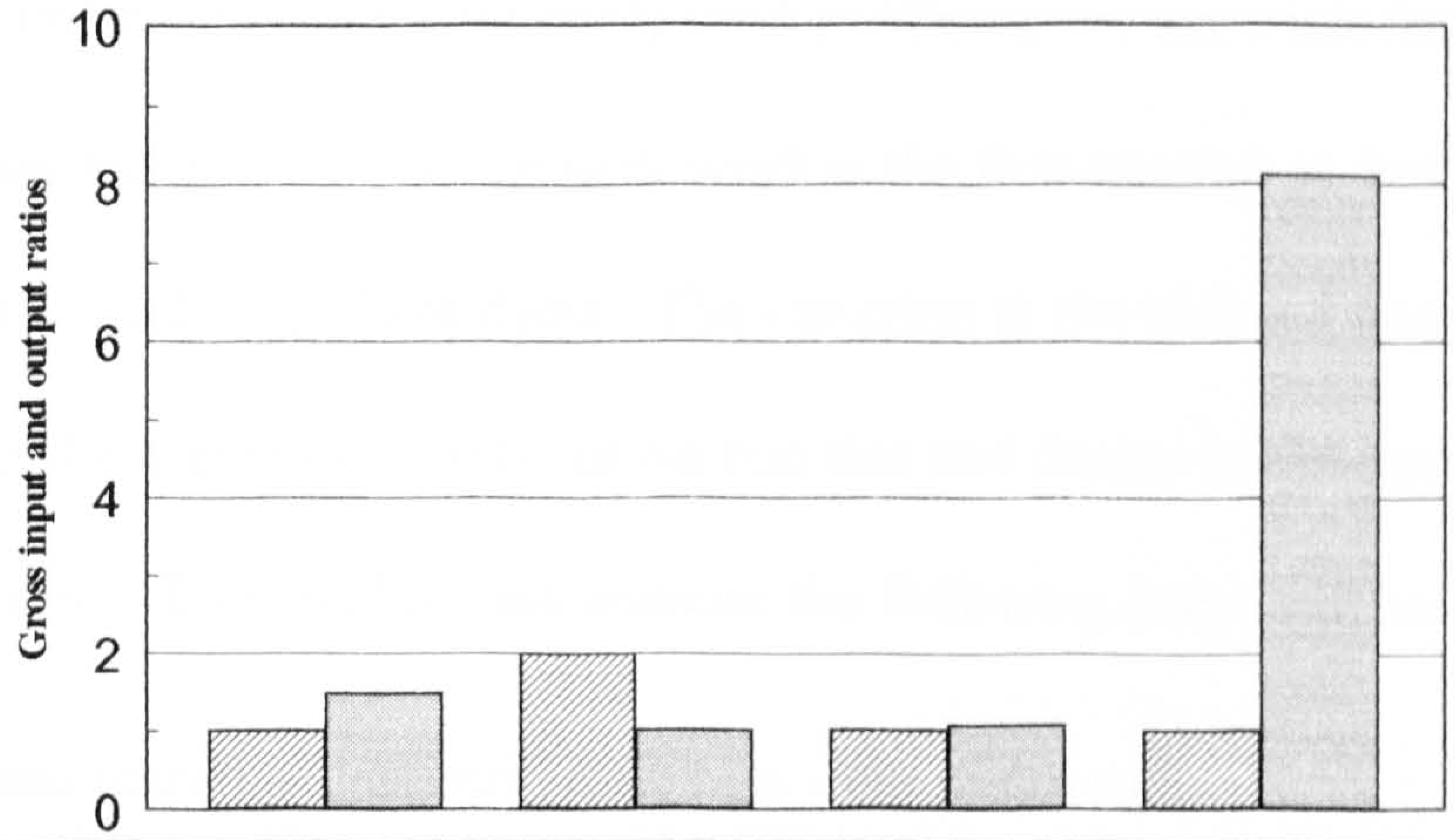
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Vitrified clay	137.83	1.00	13,615,900	1.98	61,135	1.00	3,280	1.00
PVC	202.26	1.47	6,868,000	1.00	65,684	1.07	26,628	8.12

Figure 8.14 Gross input and output ratios for systems producing 100 mm (internal diameter) sewer pipes during the lifetime of a house - per metre run



Sewer pipes	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Vitrified clay	1.00	1.00	1.00	1.00
PVC	3.40	2.34	5.20	13.28

Figure 8.15 Gross input and output ratios for systems producing yard gullies during the lifetime of a house - per gulley



Yard gullies	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Vitrified clay	1.00	1.98	1.00	1.00
PVC	1.47	1.00	1.07	8.12

By comparing Figures 8.12 and 8.14 it is clear that when judged over the expected lifetime of a house, the existing advantage of the system producing vitrified clay pipes is enhanced at the expense of the equivalent PVC system. Similar comparisons between Figures 8.13 and 8.15 show that the system producing vitrified clay yard gullies appears more favourably and with the exception of carbon dioxide emissions outperforms the equivalent PVC system.

Before any firm conclusions are made, however, it should be borne in mind that the above analysis is not a complete life-cycle analysis and does not take account of the possibility that PVC may be re-cycled, nor of the variety of acceptable installation procedures. For example, current practice allows for sewer pipes to be laid on a bed of sand or gravel or encased in concrete. Including additional materials will undoubtedly affect the final overall conclusions.

8.5 Roof drainage materials *(drainpipes & gutters)*: *aluminium, PVC*

Aluminium and PVC are commonly used as alternative materials for the manufacture of drainpipes and gutters. The present work is the first attempt at describing the performance of systems producing these items. The variation in the size and design of drainpipes and gutters make it expedient to focus on one size and design in common use when making comparisons. To complete this exercise the following items will be considered:

a) a 68 mm (external diameter) drainpipe - per metre run,
(based on data for 1.83 m aluminium and 4 m PVC lengths)

b) a 100 mm half round gutter - per metre run
(based on data for 1.83 m aluminium and 4 m PVC lengths)

The gross input and output ratios for the systems producing the above drainpipes and gutters are derived from Appendices 66, 67, 75, and 76. These ratios are given in Tables 8.12 and 8.13 respectively, and represented graphically in Figures 8.16 - 8.17.

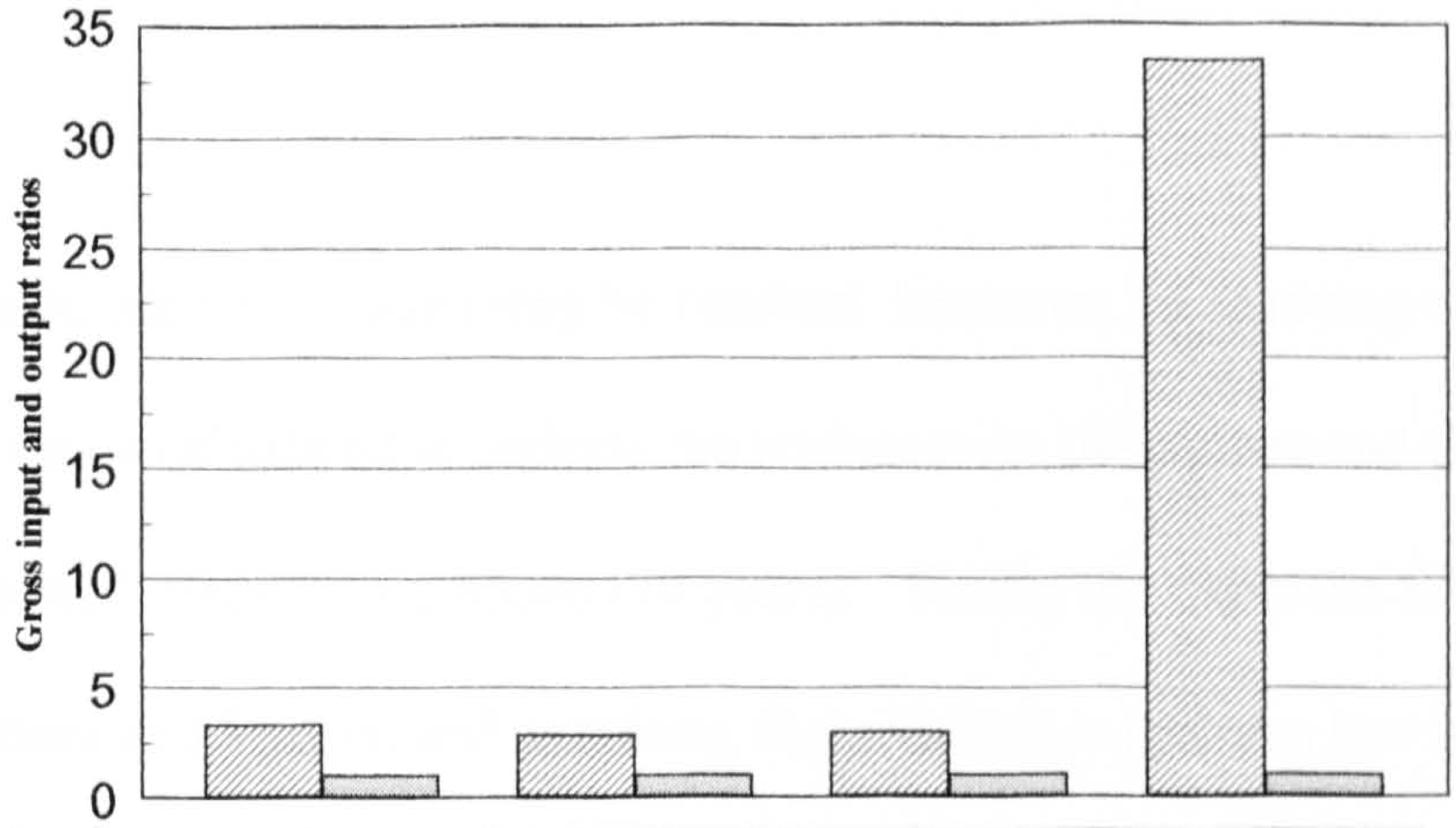
Table 8.12 Selected gross inputs and outputs for systems producing 68 mm (external diameter) drainpipes - per metre run

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Aluminium	157.39	3.29	4,852,700	2.83	49,338	2.92	354,525	33.42
PVC	47.88	1.00	1,712,100	1.00	16,888	1.00	10,609	1.00

Table 8.13 Selected gross inputs and outputs for systems producing 100 mm half round gutters - per metre run

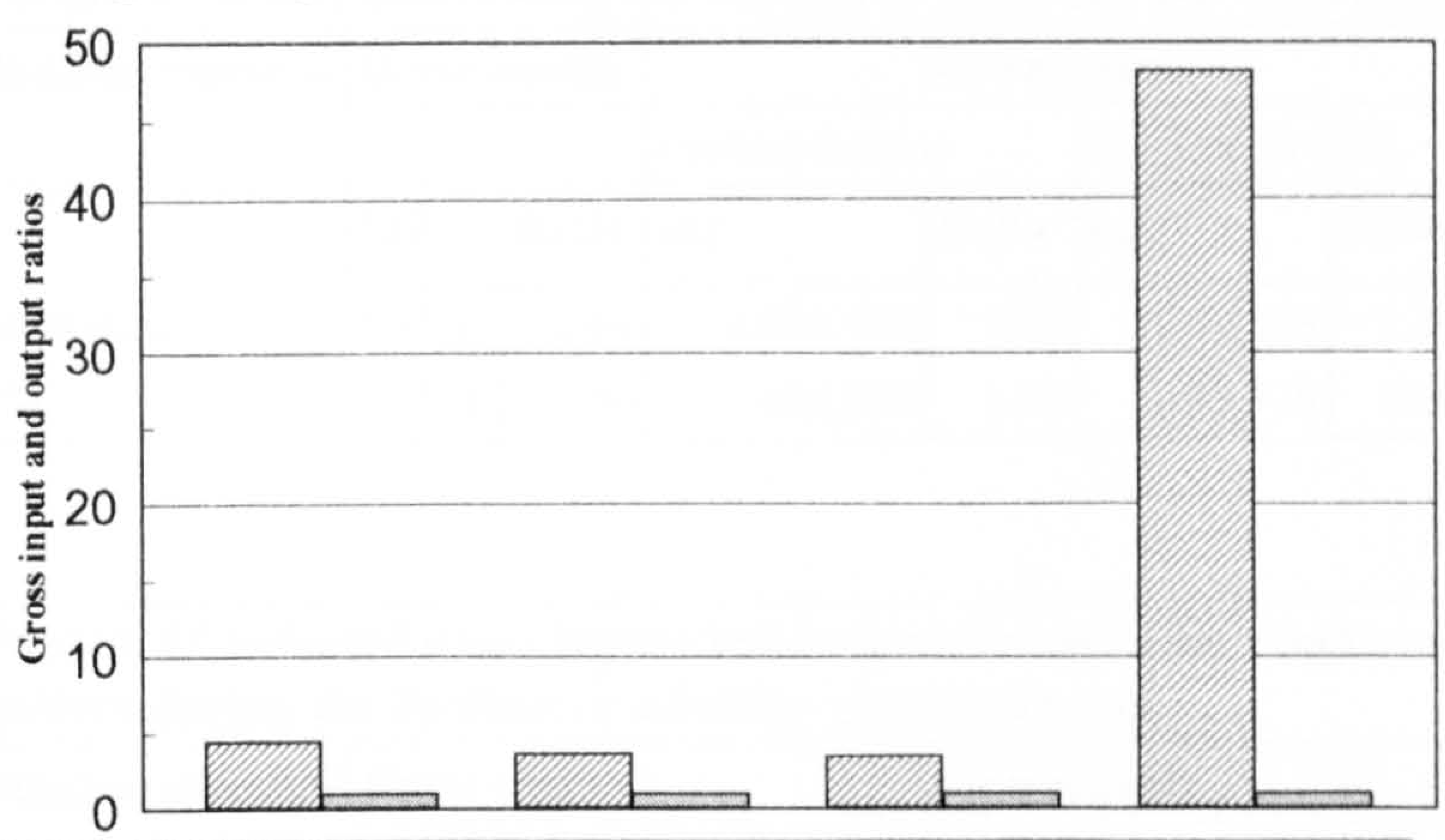
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Aluminium	192.00	4.47	5,543,200	3.61	52,022	3.43	458,849	48.17
PVC	43.00	1.00	1,537,400	1.00	15,165	1.00	9,526	1.00

Figure 8.16 Gross input and output ratios for systems producing 68 mm (external diameter) drainpipes - per metre run



Drainpipes	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Aluminium	3.29	2.83	2.92	33.42
PVC	1.00	1.00	1.00	1.00

Figure 8.17 Gross input and output ratios for systems producing 100 mm half round gutters - per metre run



Gutters	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Aluminium	4.47	3.61	3.43	48.17
PVC	1.00	1.00	1.00	1.00

Again, using the gross input and output totals as performance indicators, it is evident from Figures 8.16 and 8.17 that systems using PVC constantly outperform equivalent aluminium systems. The consistent agreement across the full range of gross input and output ratios, for both drainpipe and gutter production, confers a significant advantage to systems using PVC.

More accurate conclusions may be reached, however, by studying revised gross input and output ratios calculated to include the replacement drainpipes and gullies required during the expected lifetime of a house (70 years). Taking the expected lifetime of PVC drainpipes and gutters as 35 years, and assuming that aluminium systems last the lifetime of the house, it is clear that two PVC systems are needed for every one aluminium. The revised gross input and output ratios are shown in Tables 8.14 and 8.15 and graphically illustrated in Figures 8.18 and 8.19.

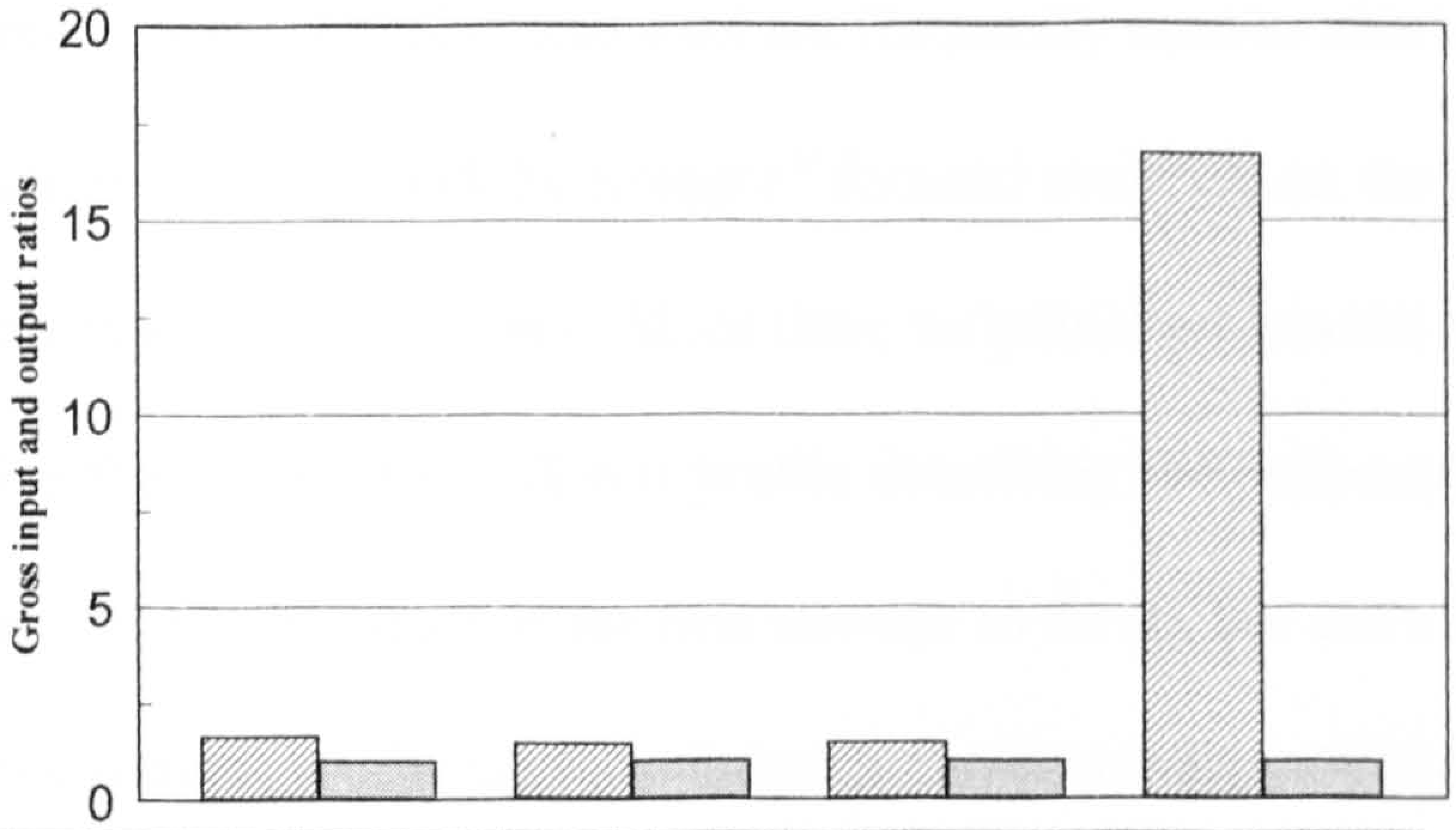
Table 8.14 Selected gross inputs and outputs for systems producing 68 mm (external diameter) drainpipes during the lifetime of a house - per metre run

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Aluminium	157.39	1.64	4,852,700	1.42	49,338	1.46	354,525	16.71
PVC	95.76	1.00	3,424,200	1.00	33,776	1.00	21,218	1.00

Table 8.15 Selected gross inputs and outputs for systems producing 100 mm half round gutters during the lifetime of a house - per metre run

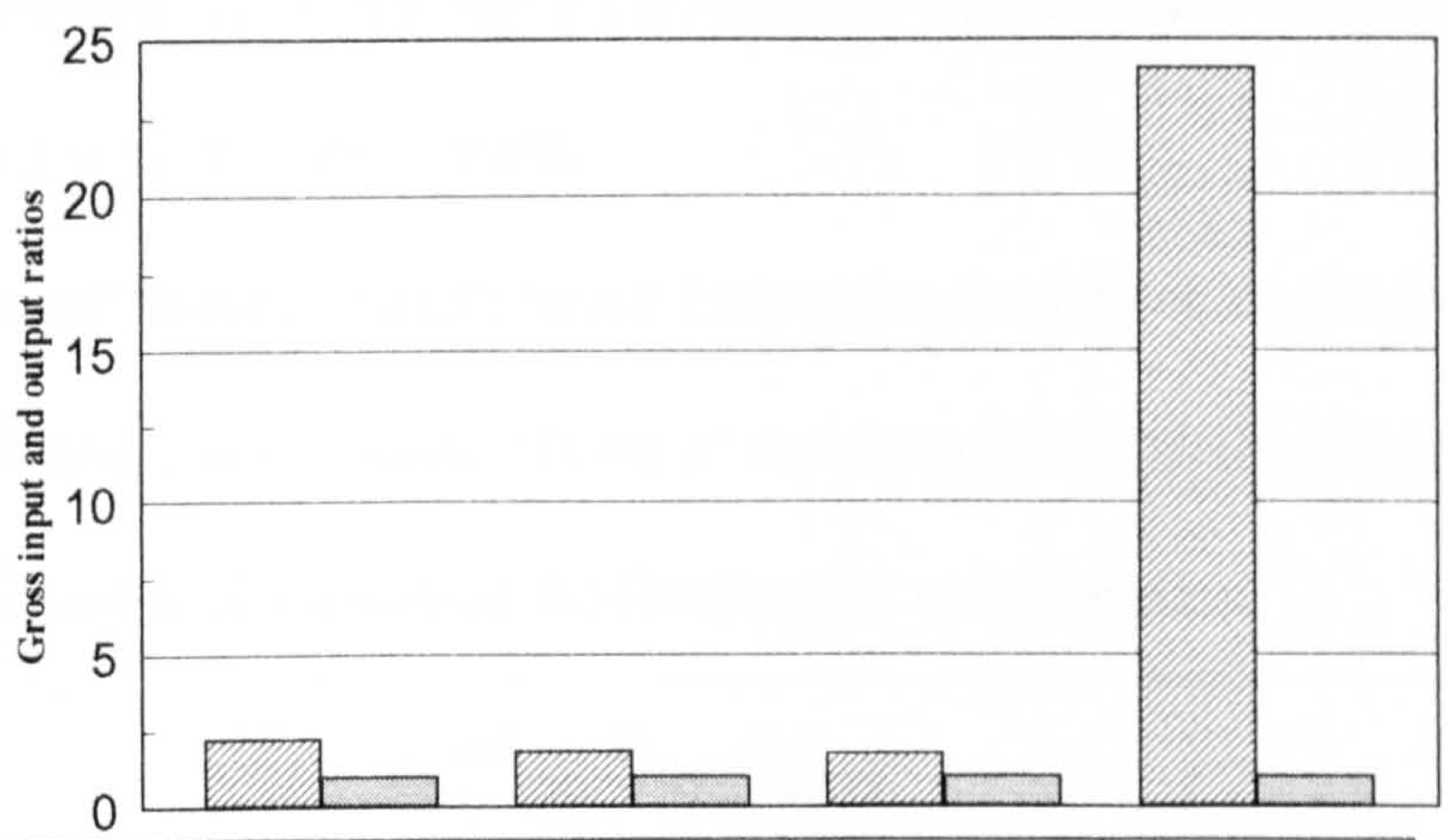
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Aluminium	192.00	2.23	5,543,200	1.80	52,022	1.72	458,849	24.08
PVC	86.00	1.00	3,074,800	1.00	30,330	1.00	19,052	1.00

Figure 8.18 Gross input and output ratios for systems producing 68 mm (external diameter) drainpipes during the lifetime of a house - per metre run



Drainpipes	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Aluminium	1.64	1.42	1.46	16.71
PVC	1.00	1.00	1.00	1.00

Figure 8.19 Gross input and output ratios for systems producing 100 mm half round gutters during the lifetime of a house- per metre run



Gutters	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Aluminium	2.23	1.80	1.72	24.08
PVC	1.00	1.00	1.00	1.00

Comparing Figures 8.16 and 8.17 with Figures 8.18 and 8.19 it is evident that the systems producing PVC drainpipes and gutters maintain their marked superiority over equivalent aluminium systems when judged over the lifetime of a house, albeit with a reduced advantage.

8.6 Lintels - single and combined: *reinforced concrete, timber and steel*

Reinforced concrete, timber and steel are frequently used as alternative materials for lintel construction. Earlier work by Kreijger[22] focused attention on the gross energy requirements of beams as a function of span. Since then, no published interest has been shown in extending this work into a full eco-profile describing the performance of lintel production systems. The present study is the first attempt to do so, but unlike Kreijger's work, compares systems producing built-in lintels carrying uniformly distributed loads for one span length only. The three lintel types to be considered are described below:

Single lintels: width x height: (100 mm x 143 mm) and (125 mm x 143 mm)

a) homogenous rectangular sections manufactured from timber and reinforced concrete:

b) I-section rolled steel joist: flange and web thickness 7 mm

The dimensions correspond to the width of typical bricks or concrete blocks, and the height of two courses of brick.

Combined lintels: manufactured from galvanised steel, dimensions as in Figure 8.20.

A combined lintel consists of two or more structural elements joined together and acting as one. Figure 8.20 illustrates the lintel under consideration.

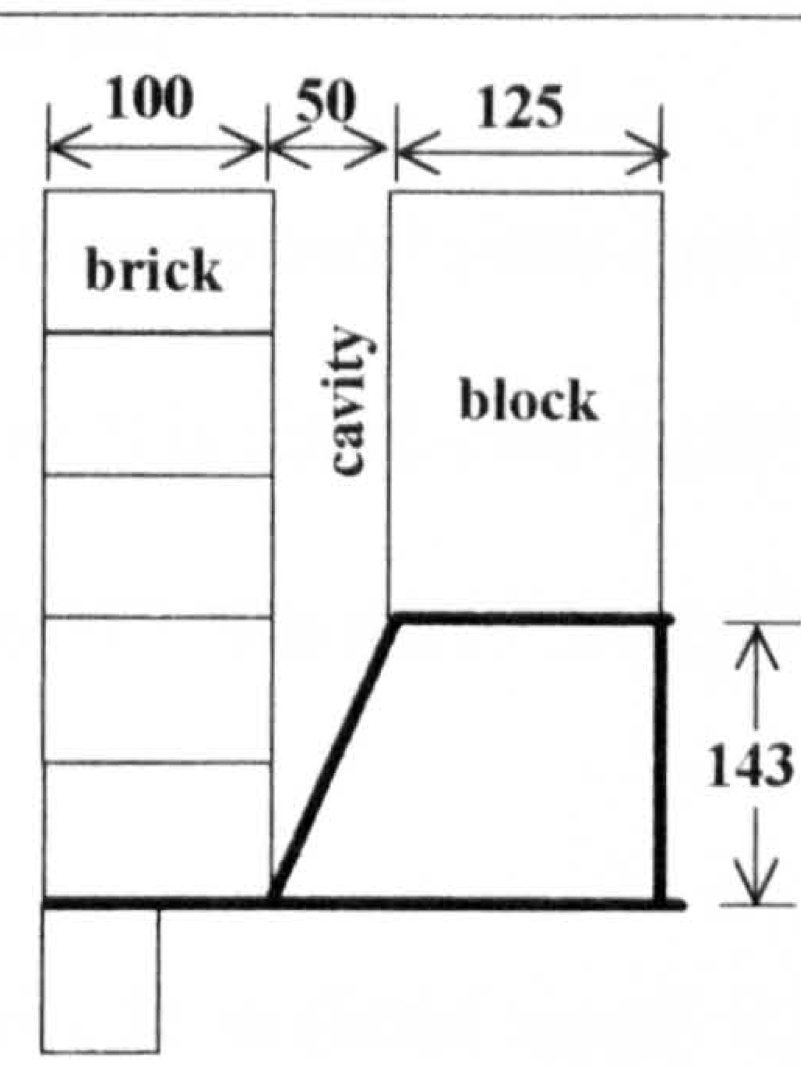


Figure 8.20 Diagram showing a combined lintel application across a cavity wall
All dimensions are in mm

For a combined lintel of the given dimensions, the safe working load at a maximum design span of 1.35 m is taken as 17,150 N (manufacturer's specification).

Single lintel systems equivalent to combined lintels: dimensions as shown in Figure 8.21. Two single lintels produced from reinforced concrete, timber or steel may be positioned alongside each other in a cavity wall to form a single lintel pair. For the purpose of comparison they may be considered as serving the same function as the combined lintel shown in Figure 8.20 and treated as equivalent systems. The configurations to be compared are shown in Figure 8.21.

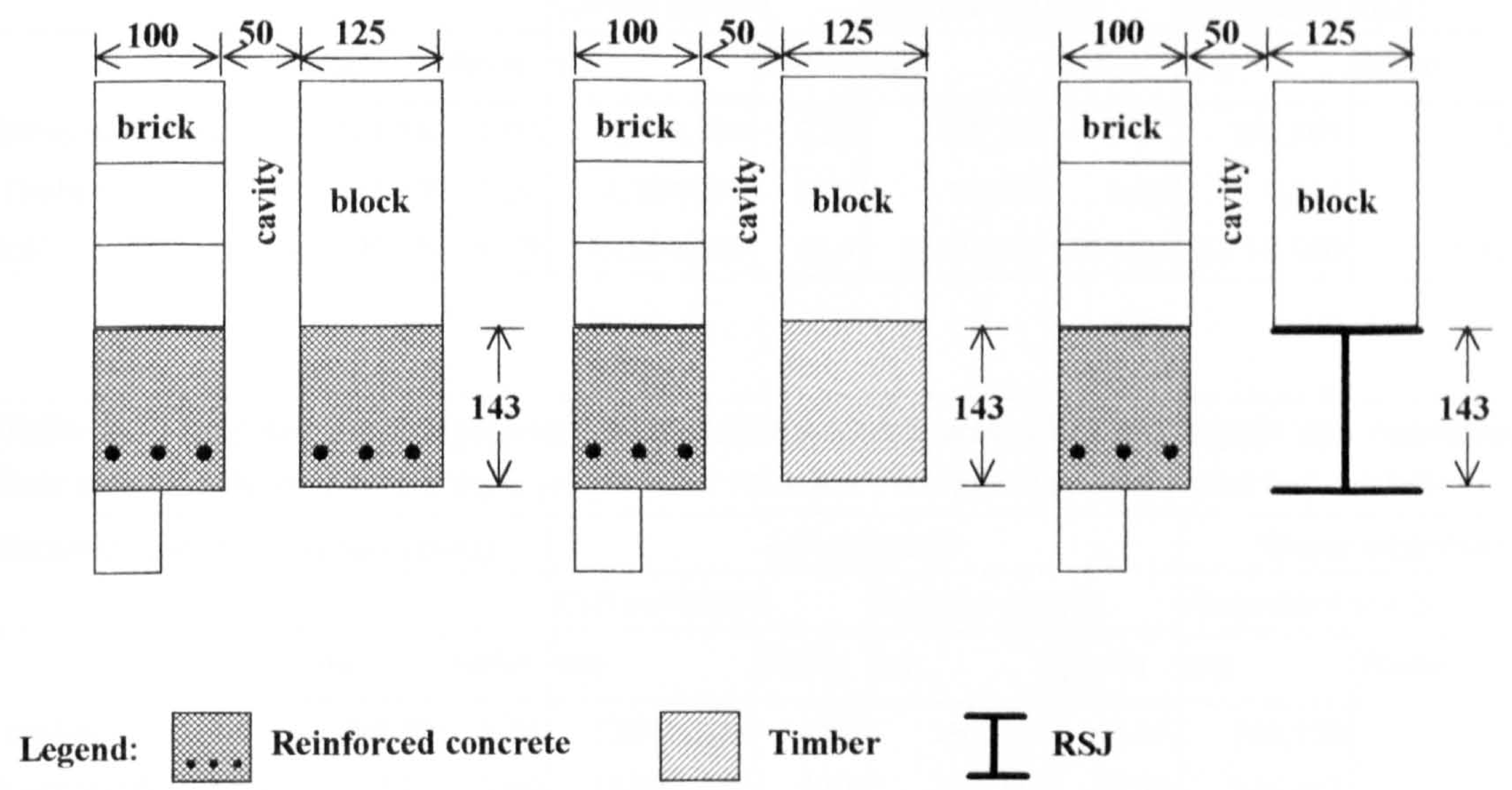


Figure 8.21 Diagram showing possible configurations for single lintel pairs
All dimensions are in mm

When comparing these single lintel pairs with the combined lintel, it is assumed that a safe working load of 17,150 N is distributed equally between the two lintels. For consistency, a safe working load of 8,575 N is assumed for single lintels throughout this work.

Using a design span of 1.35 m (lintel length 1.50 m) and the specified safe working loads, it may be shown that all three lintel types function safely below the maximum strength of the materials, and in particular, comply with British Standards safety limits.[68]

The gross input and output ratios for the systems producing (100 mm x 143 mm) single lintels are derived from data in Appendices 36, 45 and 53. These ratios are given in Table 8.16 and represented graphically in Figures 8.22 and 8.23. The gross input and output ratios for the systems producing the combined lintel and equivalent single lintel pairs are derived from Appendices 38 and 57. These ratios are given in Table 8.17 and represented graphically in Figure 8.24.

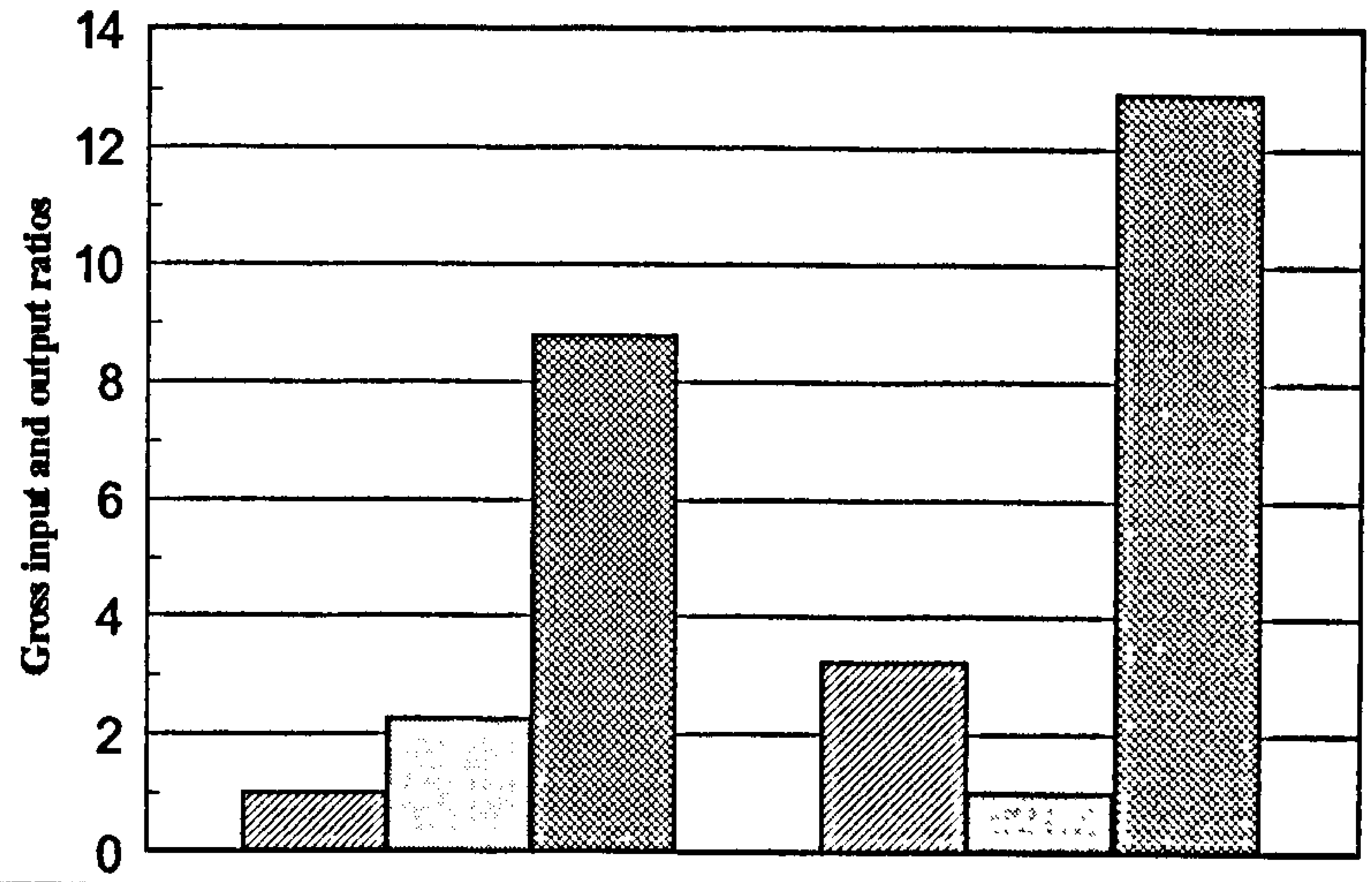
Table 8.16 Selected gross inputs and outputs for systems producing single lintels - per 1.50 m metre length

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Reinforced concrete	101.54	1.00	8,895,100	3.22	144,790	9.71	161,495	122.9
Timber	227.07	2.24	2,764,000	1.00	14,914	1.00	1,314	1.00
RSJ	890.75	8.77	35,654,000	12.9	3,090,600	207.23	4,618,600	3,514.92

Table 8.17 Selected gross inputs and outputs for systems producing single pair and combined lintels - per 1.50 m metre length (single pairs: outer leaf - reinforced concrete, inner leaf - as below)

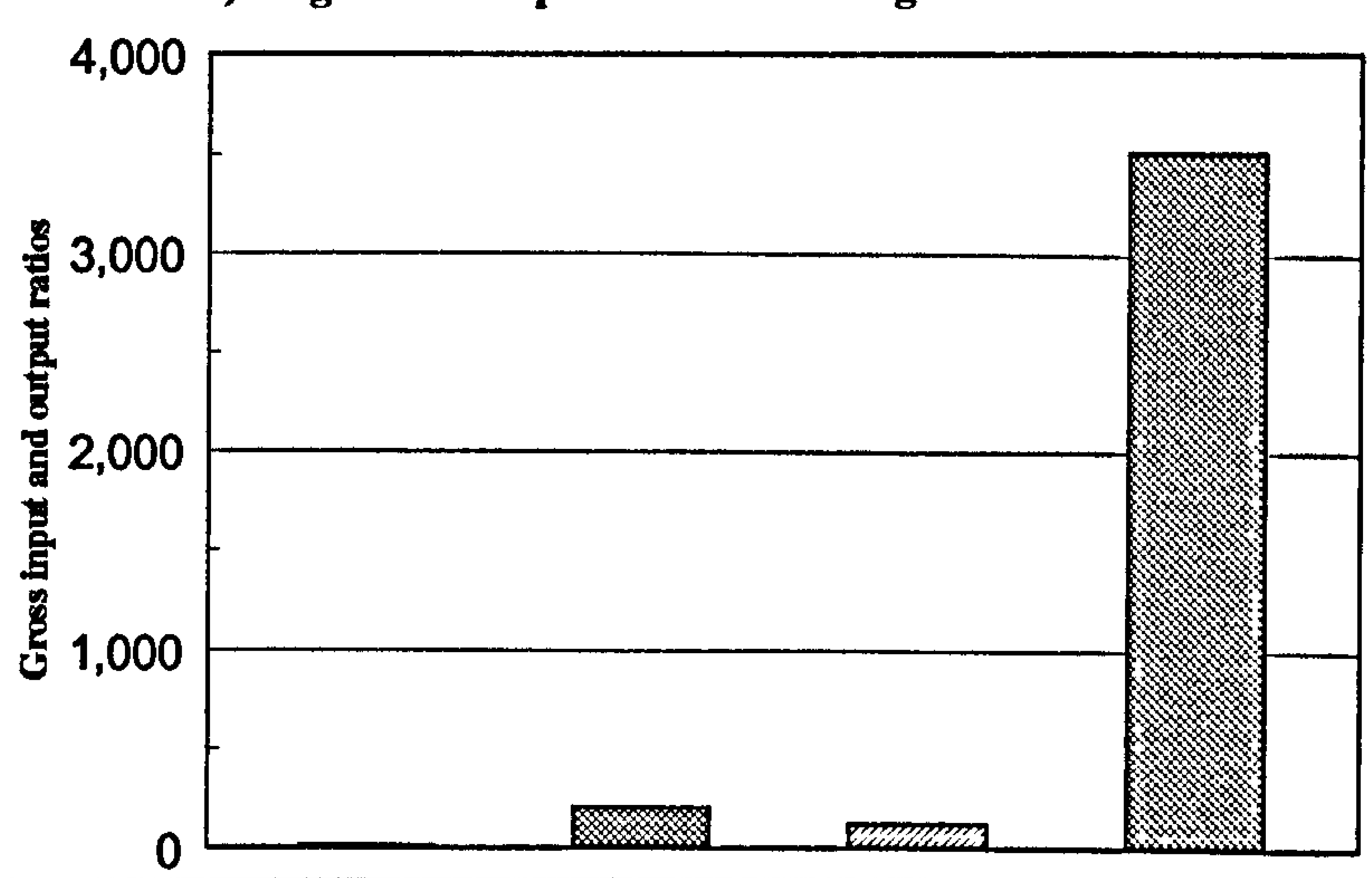
Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Timber	385.38	1.71	12,350,100	1.00	163,432	1.00	163,138	1.00
Reinforced concrete	225.23	1.00	19,897,300	1.61	313,713	1.92	346,447	2.12
RSJ	1,127.72	5.01	4,997,100	4.05	3,705,300	22.67	5,482,300	33.61
Combined - Galvanised steel	550.28	2.44	23,455,500	1.90	1,571,400	9.62	2,289,100	14.03

Figure 8.22 Gross input and output ratios for systems producing (100 mm x 143 mm) single lintels - per 1.50 metre length



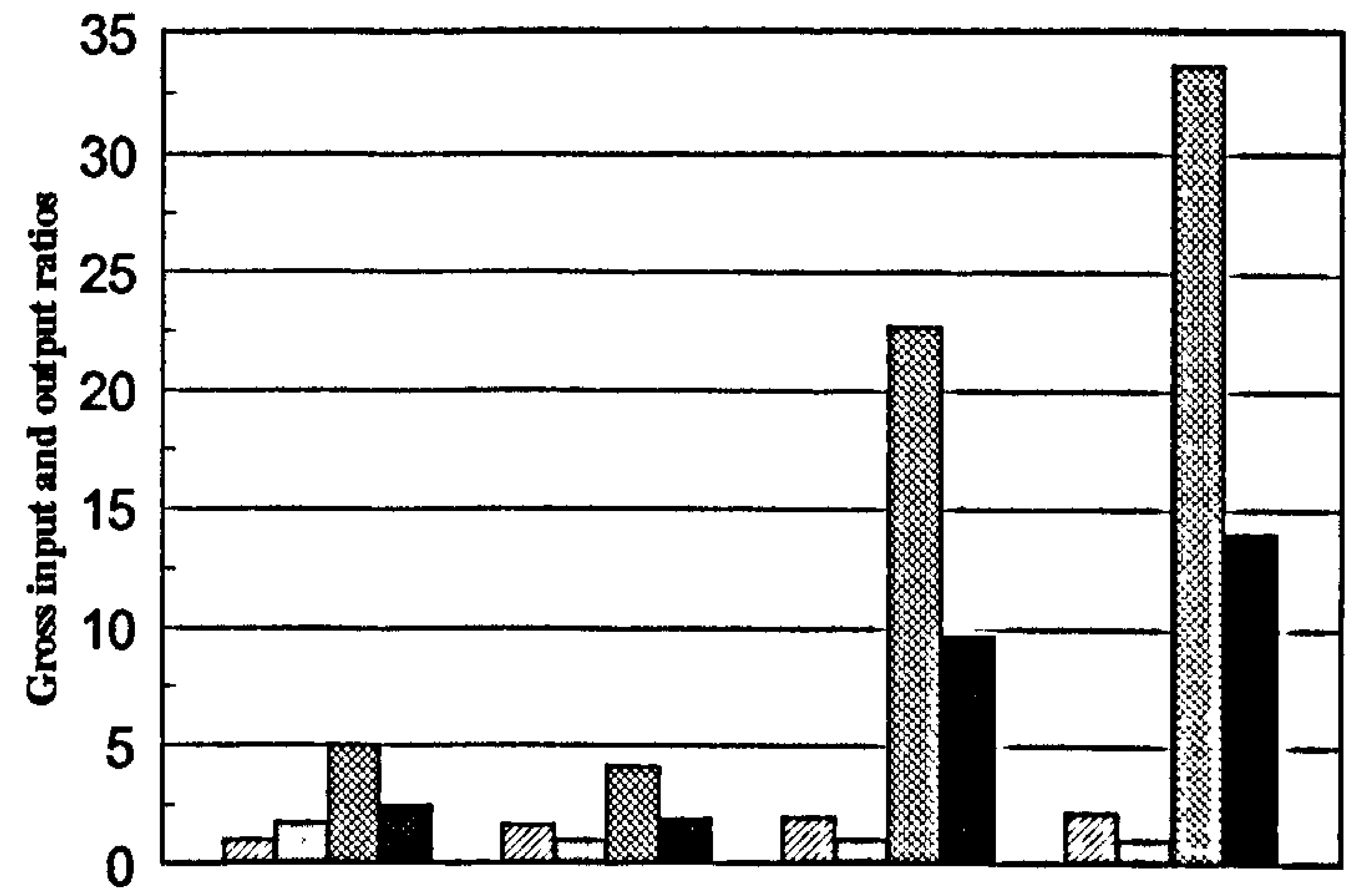
Lintels	Gross energy	Carbon dioxide
Reinforced concrete	1 00	3.22
Timber	2 24	1.00
RSJ	8 77	12 90

Figure 8.23 Gross input and output ratios for systems producing (100 mm x 143 mm) single lintels - per 1.50 metre length



Lintels	Sulphur dioxide	Suspended solids
Reinforced concrete	9.71	122 90
Timber	1 00	1.00
RSJ	207 23	3,514 92

Figure 8.24 Gross input and output ratios for systems producing single pair and combined lintels- per 1.50 metre length



Lintels - Inner leaf/combined	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Reinforced concrete	1.00	1.61	1.92	2.12
Timber	1.71	1.00	1.00	1.00
RSJ	5.01	4.05	22.67	33.61
Galvanised steel - combined	2.44	1.90	9.62	14.03

With reference to Figures 8.22 and 8.23, it is clear that with the exception of gross energy inputs, the order of increasing performance for single lintel systems reads: *RSJs*, *reinforced concrete*, *timber*. However, the use of gross energy inputs as the sole performance indicator, adjusts the order to read *RSJs*, *timber*, *reinforced concrete*. Although the system producing RSJs is clearly outperformed, the results are inconclusive with the timber and reinforced concrete production systems both claiming competing advantages.

It is interesting to note that in Kreijger's study, the gross energy requirement for the production of timber lintels is less than that for reinforced concrete lintels. Using his results the order of increasing merit reads: *RSJs*, *reinforced concrete*, *timber*. These results differ from the present study. Unfortunately, there is insufficient information in Kreijger's paper to explain the reversed order for reinforced concrete and timber. One possible explanation is that Kreijger may have failed to include timber feedstock energy in his calculations. Making this omission in the present work produces similar conclusions.

Figure 8.24 demonstrates that the comparison between systems producing galvanised steel combined lintels and single lintel pair equivalents, reaches similar overall conclusions to those already reached for single lintel systems. Using gross energy inputs, the ascending order of performance (omitting the reinforced concrete outer leaf) reads: *RSJ*, *galvanised steel* (combined), *timber*, *reinforced concrete*. For the remaining gross inputs or outputs, the order becomes: *RSJ*, *galvanised steel* (combined), *reinforced concrete*, *timber*. Clearly these results are inconclusive with the timber and reinforced concrete systems once again claiming competing advantages.

Since the expected lifetimes of a house and the above lintel systems are similar, comparisons over the lifetime of a house will produce identical conclusions. It must be noted, however, that a complete life-cycle analysis might produce different conclusions. For example, RSJs and galvanised steel combined lintels may be re-cycled or used again.

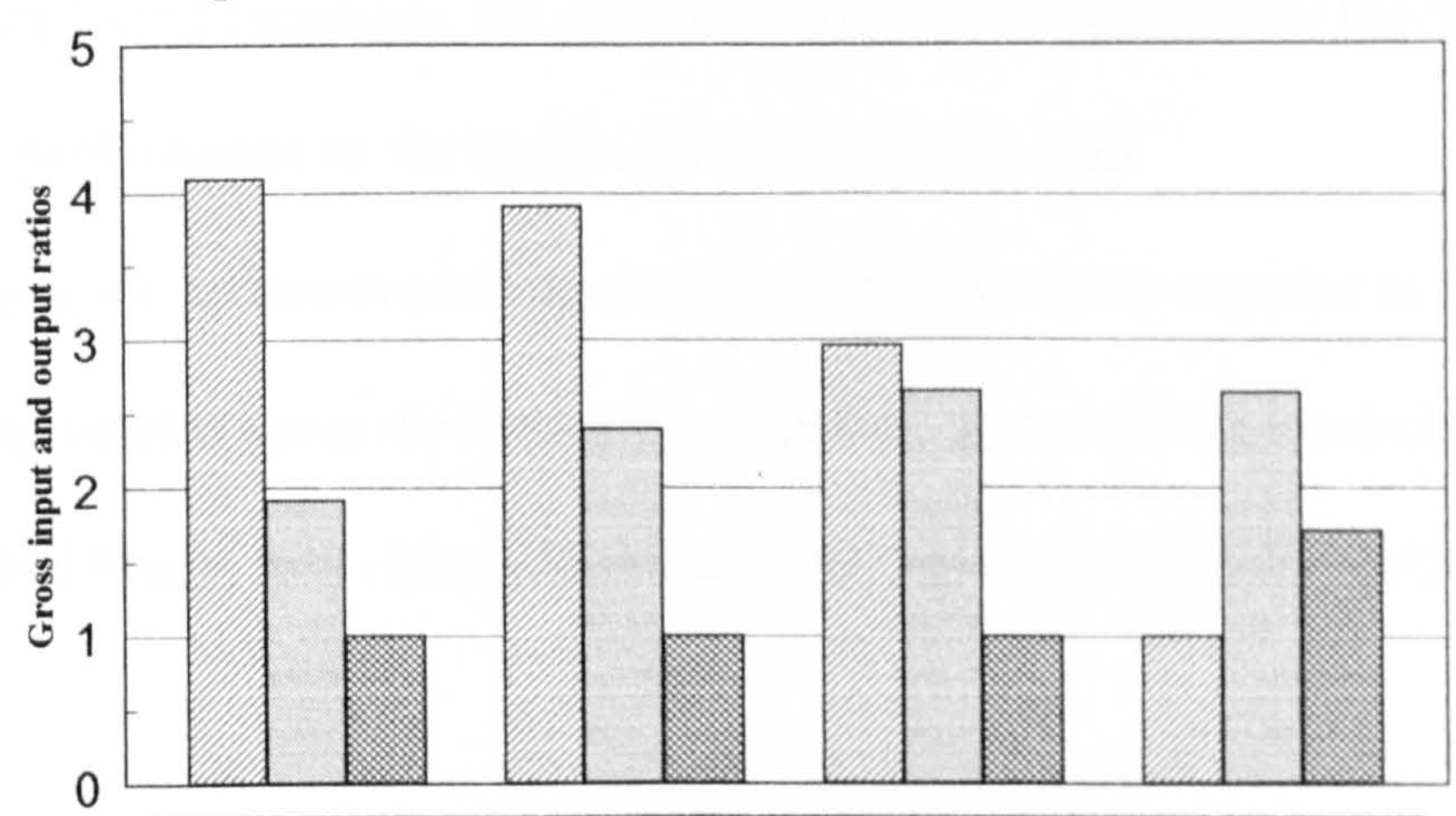
8.7 Building blocks: *clay bricks, dense concrete blocks, aerated concrete blocks*

Clay bricks, dense concrete blocks and aerated concrete blocks may be used as alternatives in the construction of walls. The gross input and output ratios for the systems producing 1 square metre of single leaf wall from these materials are derived from Appendices 21, 32, and 34 respectively. These ratios are given in Table 8.18 and represented graphically in Figure 8.25.

Table 8.18 Selected gross inputs and outputs for systems producing 100 mm building blocks - per square metre single leaf wall

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Clay bricks	735.41	4.09	58,068,300	3.90	370,692	2.96	54,423	1.00
Aerated concrete blocks	344.38	1.92	35,546,100	2.39	331,128	2.65	143,598	2.64
Dense concrete blocks	179.70	1.00	14,883,200	1.00	125,042	1.00	93,074	1.71

Figure 8.25 Gross input and output ratios for systems producing building blocks - per square metre single leaf



Building blocks	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Clay bricks	4.09	3.90	2.96	1.00
Aerated concrete blocks	1.92	2.39	2.65	2.64
Dense concrete blocks	1.00	1.00	1.00	1.71

Before the three systems are compared it is important to understand that not all comparisons are necessarily valid as the blocks are designed with different purposes in mind. Load bearing walls take advantage of the superior compressive strength of clay bricks and dense blocks. In contrast, walls carrying relatively low loads and designed as a thermal barrier, such as the inner leaf of a cavity wall, take advantage of the high thermal resistance of aerated blocks. Nonetheless, dense blocks are sometimes substituted for aerated blocks as the inner leaf of cavity walls carrying high loads. Thus, it is valid to consider comparisons between:

a) dense blocks and clay bricks

b) dense blocks and aerated blocks,

but not between clay bricks and aerated blocks.

Restricting comparisons to these two cases it may be concluded from Figure 8.25 that:

a) ignoring suspended solid emissions, the system producing dense concrete blocks has an overall superior performance to the system producing clay bricks

b) the performance of the system producing dense concrete blocks is superior to that of the system producing aerated concrete blocks. Nonetheless, with superior insulation properties, aerated blocks may claim additional advantages over a full life-cycle.

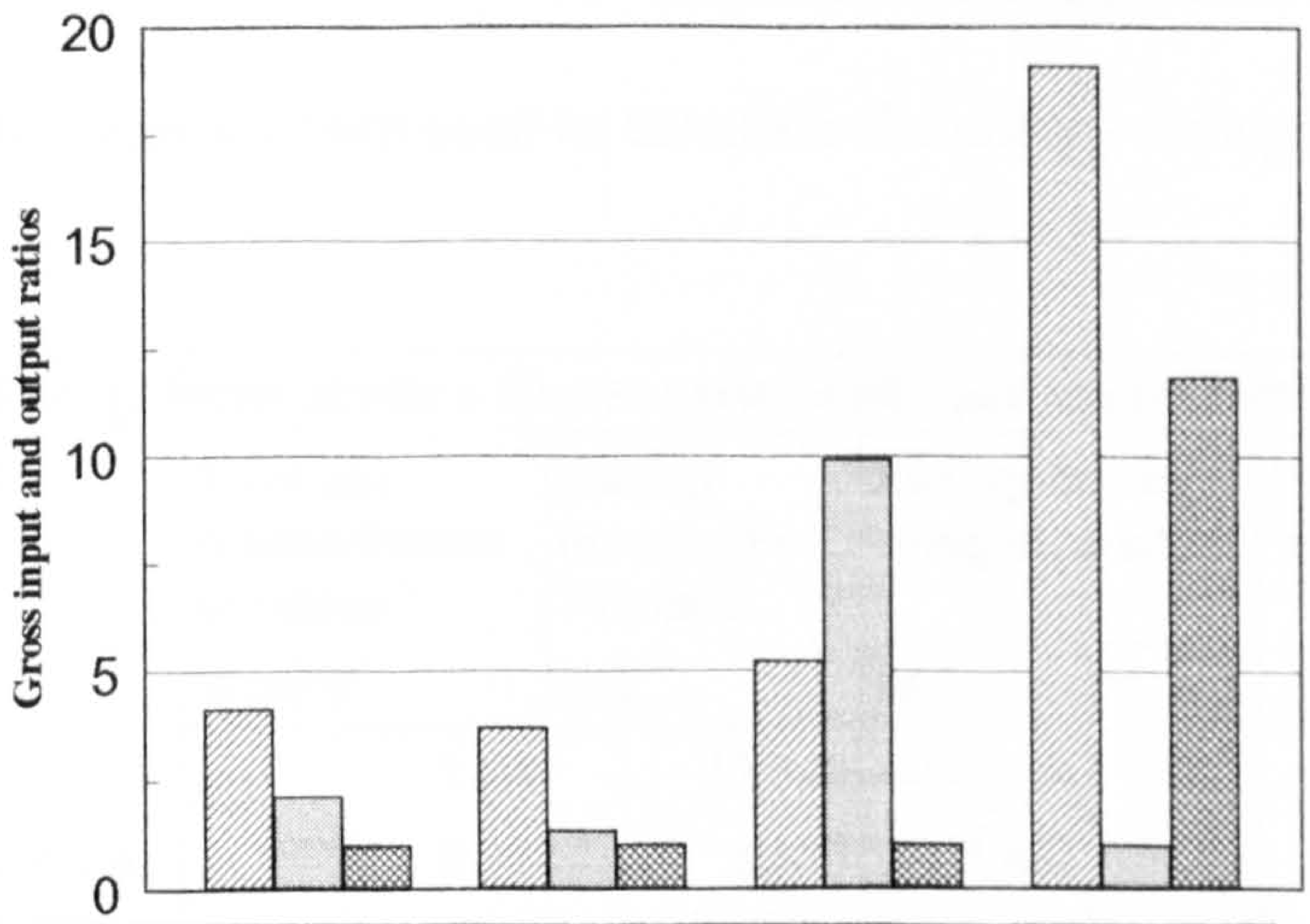
8.8 Insulation materials: *glass fibre wool, expanded polystyrene foam, polyurethane foam*

To comply with current Building Regulations one or more of the above insulation materials are normally incorporated into the design of a modern house. For a fair comparison these materials must be used for equivalent functions, such as the infill to a cavity wall. Consider the systems producing 1 square metre of the above insulants for a 50 mm cavity. The gross input and output ratios for these systems are derived from Appendices 43, 83 and 85. These ratios are given in Table 8.19 and represented graphically in Figure 8.26.

Table 8.19 Selected gross inputs and outputs for systems producing 50 mm thick insulation materials - per square metre

Building material	Gross energy		Air emissions				Water emissions	
			Carbon dioxide		Sulphur dioxide		Suspended solids	
	MJ	Ratio	mg	Ratio	mg	Ratio	mg	Ratio
Polyurethane foam	164.81	4.13	7,423,900	3.68	60,405	5.22	62,189	19.06
Expanded polystyrene foam	84.76	2.12	2,673,700	1.33	114,587	9.91	3,262	1.00
Glass fibre wool	39.94	1.00	2,015,200	1.00	11,564	1.00	38,534	11.81

Figure 8.26 Gross input and output ratios for systems producing 50 mm thick insulation materials- per square metre



Insulation material	Gross energy	Carbon dioxide	Sulphur dioxide	Suspended solids
Polyurethane foam	4.13	3.68	5.22	19.06
Expanded polystyrene foam	2.12	1.33	9.91	1.00
Glass fibre wool	1.00	1.00	1.00	11.81

Inspection of these results reveals two noticeable features:

1. the relatively poor performance of the polyurethane foam production system
2. with the exception of suspended solid emissions, the overall superiority of the system producing glass fibre wool.

However, these conclusions are of limited value as they fail to consider the energy saving performance of the insulants during a complete life-cycle. This omission highlights an important difference between the present eco-profile and a full life-cycle analysis.

To illustrate this point further, consider the energy losses over the lifetime of a house, say seventy years, across 1 square metre of insulated and uninsulated 50 mm cavity wall. For the purpose of discussion the following assumptions are made:

- cavity wall profile: outer leaf - 20 mm cement render/100 mm dense concrete block
  inner leaf - 140 mm aerated concrete block
- all energy losses occur during the six winter months
- the average winter temperature gradient across the wall is 13° C

Standard U-values are used in Table 8.20 to calculate energy losses with and without insulants. These values are then used to calculate the energy savings arising from the use of

Table 8.20 Energy losses across a 50 mm cavity wall - per square metre

Cavity infill	Thermal transmittance U-values [1] W/m²K	Energy losses over 70 years MJ	Energy saving using insulation MJ	%	Production energy as % of energy saving
Air	0.86	12,340	---------	-----	----------
Polyurethane foam	0.34	4,879	7,461	60	2.21
Expanded polystyrene foam	0.43	6,170	6,170	50	1.37
Glass fibre wool	0.45	6,457	5,883	48	0.68

[1] Derived from Digest108: Standard U-values, Building Research Establishment, 1991
Note: Maximum allowed U-value = 0.45 W/m²K (1990 Building Regulations, Approved Document L, England & Wales)

the different insulants. The importance of the gross input and output figures in Table 8.19 gains perspective by comparing the gross production energies with these energy savings. From Table 8.20 it is evident that the gross production energies represent a very small proportion of the energy savings. Moreover, it is clear that any one of these insulants will satisfy Building Regulations and produce the desired energy savings. Thus, in the context of a complete life-cycle the notion of a superior production system loses meaning.

8.9 Effect of substituting alternative materials on house eco-profiles

Comparing the results in Sections 8.2 - 8.8 with the material inputs to house construction in Tables 6.2 and 6.3, it is evident that most of the materials offering significant reductions in gross inputs and outputs are already included. Nonetheless, advantages may be gained by the following substitutions:

a) dense concrete blocks for clay bricks

b) timber or reinforced concrete lintels for RSJs and galvanised steel combined lintels.

The sensitivity analysis in Section 7.3 supports the proposed substitution of dense concrete blocks for clay bricks. However, since RSJs and galvanised steel combined lintels make a relatively small contribution to the gross input and output totals, the proposed substitution in b) above will produce even smaller savings and will therefore not be made.

Although life-cycle analysis is not concerned with the competing aesthetic claims of different materials, it is normal building practice to use a cement render to enhance the appearance of exterior walls constructed from concrete blocks. The proposed use of dense concrete blocks is therefore accompanied by additional mortar inputs.

Finally, although strictly not a substitution, to comply with current Building Regulations it is necessary to include cavity wall and ground floor insulation materials in the inventory of proposed amendments to Tables 6.2 and 6.3. These amendments are summarised in Tables 8.21 and 8.22 below.

Table 8.21 Amendments to Table 6.2 ***Material inputs to bungalow house construction***

Materials	Deletions	Additions	Mass kg
65 mm clay facing and common bricks	31,973 kg		-31,973
Dense concrete blocks (440x215x100) mm		213.2 m^3	41,361
20 mm Ready mixed cement:lime:sand mortar		4,284 kg	4,284
50 mm Expanded polystyrene foam cavity wall and ground floor insulation.		186 m^2	140
		Total	13,812
		Less 5 % waste on bulk items	-651
		Net change	13,161

Table 8.22 Amendments to Table 6.3 ***Material inputs to detached house construction***

Materials	Deletions	Additions	Mass kg
65 mm clay facing and common bricks	40,163 kg		-40,163
Dense concrete blocks (440x215x100) mm		267.8 m^3	51,953
20 mm Ready mixed cement:lime:sand mortar		6,930 kg	6,930
50 mm Expanded polystyrene foam cavity wall and ground floor insulation.		178 m^2	134
		Total	18,854
		Less 5 % waste on bulk items	-891
		Net change	17,963

The effect of these amendments on the gross inputs and outputs associated with the construction of the bungalow house and the two storey detached house are detailed in Appendices 90 to 92. A selection of the amended gross inputs and outputs are shown in Table 8.23.

Table 8.23 A comparison of the amended gross inputs and outputs to building construction						
	per building			per m² floor space		
Input/Output	**Bungalow**	**House**	**% change**	**Bungalow**	**House**	**% change**
Gross inputs						
Energy (GJ)	454.30	536.58	18.08	5.22	4.39	-15.90
Raw materials (g)						
Sand	53,988,900	56,267,000	4.22	620,561	460,074	-25.86
Limestone	138,561,200	145,785,800	5.21	1,592,600	1,192,000	-25.15
Clay	646,225	600,944	-7.01	7,428	4,914	-33.84
Gross outputs (g)						
Air emissions						
Carbon dioxide	31,692,800	39,757,400	25.45	364,281	325,081	-10.76
Sulphur dioxide	285,834	365,746	27.96	3,284	2,991	-8.92
Water emissions						
Suspended solids	621,073	942,345	51.73	7,139	7,705	7.93

In the comparison between the bungalow house and the detached house, these results follow a similar pattern as the original data set in Table 7.1. However, considerable changes to the original gross inputs and outputs per building are noted as shown in Table 8.24.

Table 8.24 Original versus amended gross inputs and outputs to building construction - per building (% change)		
Input/Output	**Bungalow**	**House**
Gross inputs		
Energy (GJ)	-17.80	-19.01
Raw materials (g)		
Sand	7.55	12.00
Limestone	38.62	50.29
Clay	-98.82	-99.13
Gross outputs (g)		
Carbon dioxide	-20.20	-20.07
Sulphur dioxide	-8.47	-9.34
Suspended solids	1.85	-1.60

The marked reduction in gross energy inputs and air emissions is attributed to the relatively low fuel consumption in the production of dense concrete blocks compared to clay brick manufacture. The pronounced reduction in gross clay inputs, paralleled by a corresponding increase in the gross inputs of sand and limestone, is attributed to the substitution of clay bricks by dense concrete blocks. On balance it may be concluded that the environmental burdens of building construction are significantly reduced by the substitution of dense concrete blocks for clay bricks.

Chapter 9

CONCLUSIONS

9.1 Overview

Primary data from commercial sources have been used in this study to produce eco-profiles containing the latest available information for both new and traditional building materials . In addition, the gross inputs and outputs associated with the production of different materials have been assembled to create detailed eco-profiles for the construction of a three bedroom bungalow house and a four bedroom detached house. Finally, eco-profiles for alternative building materials have been compared and the effect of their substitution on the eco-profiles of house construction considered. The results of this work are recorded in the Appendices and have been discussed in earlier chapters. Nonetheless, attention is drawn to the following major conclusions.

9.2 Eco-profiles of house construction

- With the exception of emissions of suspended solids, the gross inputs and outputs per square metre of floor space for detached house construction, are significantly less than those for bungalow construction; see Table 7.1.
- The gross energies for both detached house and bungalow construction fall in the range of published values detailed in Table 7.2. However, it is difficult to make strict comparisons as many of the earlier values relate to other countries, different types of building, or use outdated primary data and fuel production efficiencies.
- The dominant material inputs to house construction have been identified in Tables 6.2 and 6.3 as belonging to the *minerals, structural clay products, concrete and mortar products*, and *timber* categories, and collectively account for 94 % of the total.

Table 9.1 presents a comparison between these material inputs and the corresponding gross energy inputs in Tables 7.3 and 7.4.

Table 9.1 Major material inputs and gross energy inputs to house construction				
Material inputs	**Mass inputs %**		**Gross energy %**	
	Bungalow	**Detached house**	**Bungalow**	**Detached house**
Minerals	23.30	19.45	1.23	0.92
Structural clay products	16.30	18.80	28.99	30.17
Concrete and mortar products	52.50	53.55	27.19	29.59
Timber products	2.13	2.25	19.73	19.44
Total	94.23	94.05	77.14	80.12

It is interesting to note that *structural clay products* and *concrete and mortar products* make approximately similar contributions to the gross energy inputs. In contrast, the total mass inputs attributed to *concrete and mortar products* are approximately three times those of *structural clay products.* These comparisons infer an intrinsic advantage is to be gained by the use of concrete products and confirm earlier results. Despite a significant mass input, *minerals* such as limestone and sand make a minor contribution to the gross energy inputs. For *timber* products the position is reversed; small mass inputs giving rise to significant gross energy inputs, most of which is attributed to wood feedstock energy.

9.3 Eco-profiles of alternative building materials

Alternative building materials have been compared over the expected lifetime of a modern house (70 years). The results of these comparisons, as discussed in Sections 8.2 - 8.8, are summarised in Table 9.2.

Table 9.2 Comparison of alternative building products during the 70 year expected lifetime of a modern house - a summary

Product	Alternative materials	Materials offering significant reductions in gross inputs and outputs
Roof tiles	Clay, concrete	Concrete
Window frames/doors	Timber (softwood), PVC, aluminium	Inconclusive - softwood or aluminium
Underground drainage:		
- sewer pipes	Clay, PVC	Clay
- yard gullies	Clay, PVC	Clay
Roof drainage:		
- drainpipes	PVC, aluminium	PVC
- gutters	PVC, aluminium	PVC
Lintels:		
- single	RSJ, timber, reinforced concrete	Timber or reinforced concrete
- combined	RSJ, timber, reinforced concrete, galvanised steel	Timber or reinforced concrete
Building blocks	Dense concrete blocks, clay bricks	Dense concrete block
	Dense concrete blocks, aerated concrete blocks	Dense concrete blocks
Insulation materials	Polyurethane foam, expanded polystyrene foam, glass fibre wool	Inconclusive

From these results the following conclusions may be drawn.

- The use of clay as a building material has considerable disadvantages. As a traditional material for the production of roof tiles and bricks it is challenged by alternative concrete products. Nonetheless, it is the preferred product for underground drainage systems.
- Wood and aluminium are the preferred materials for window frame construction despite competition from 'easy care' alternatives such as PVC.

- PVC roof drainage systems offer considerable advantages over aluminium alternatives.
- Wood or reinforced concrete are the preferred products for lintel construction.
- Comparisons between insulation materials are inconclusive although expanded polystyrene foam and glass fibre wool are preferred to polyurethane foam. However, when considered over a complete life-cycle, the results are meaningless since any one of the three insulants will produce considerable energy savings far in excess of the initial energy consumed in their production.

9.4 Effect of alternative building materials on house eco-profiles

From the discussion in Chapter 8.9 it is clear that for the two types of house considered, many of the superior building products have already been incorporated into the builder's schedules, thereby reducing the scope for variation. Nonetheless, it is evident from Table 8.24 that significant reductions in the gross inputs and outputs to house construction may be made by substituting dense concrete blocks for clay bricks.

9.5 Recommendations for further work

Although this study has considered in great detail the inventory flows across extended industrial systems producing building materials, it is of necessity a 'snapshot' description of a constantly changing scene. Any conclusions will be sensitive to improvements in the design of industrial processes and fuel production efficiencies. Moreover, most of the primary data have been obtained from single sources and are not necessarily representative of the industry. Furthermore, this investigation has been directed towards an eco-profile of building materials, rather than a life-cycle analysis, and restricted to a comparison between two building types. These limitations both define the boundaries of the initial project and indicate areas of opportunity for further work. Some possible suggestions for extended study include the following.

- To study the effect of using updated fuel production efficiencies on the final conclusions.
- By considering the gross inputs and outputs over a complete life-cycle, to develop the study into a full life-cycle analysis.
- To extend the database by including additional sources of primary data and to calculate industry average inputs and outputs.
- To consider other types of building. For example, multi-storey blocks and terrace houses.
- To consider other building materials and alternative structural designs. For example, the use of traditional stone and timber facade houses.
- In anticipation of possible regulatory limits to air emissions from transport operations, to disaggregate the gross air emissions and calculate the separate contributions arising from *process* and *transport* operations.

APPENDICES

Introduction

The following Appendices include data sets describing the gross inputs and outputs associated with:

- the production, delivery and use of fuels
- road, rail and waterborne transport operations
- the production and delivery of the different materials used in modern house construction
- the construction of a three bedroom bungalow house and a four bedroom detached house

The data are presented under the seven main headings, *Energy*, *Fuels*, *Feedstocks*, *Raw materials*, *Air emissions*, *Water emissions*, and *Solid waste production*, as described in Section 2.8. Flow diagrams, where used, refer to the accompanying data set.

Notes

1. Raw material inputs of *air* and *nitrogen* refer to *compressed air* and *separated nitrogen*.
2. The environmental burdens associated with the use of sawdust and chippings as a fuel in Appendix 47 are included in the accompanying data set.
3. The flow charts and data sets for the production and delivery of kiln dried sawn timber, Appendices 44 and 46, are based on the following approximate water content for green timber: [69]

   Sitka spruce 25 %

   Redwood 50 %

   The water content of kiln dried timber in both cases is 5 %.

Appendix 1 Fuels

Gross inputs and outputs associated with the production, delivery and use of fuels/MJ
Totals may not agree because of rounding errors

Input/output	Units	Fuel					
		Coal	Coke	Natural gas	Man' gas	Heavy fuel oil	Medium fuel oil
Energy							
Electricity - production & delivery	MJ	—	—	—	—	—	—
Electricity - delivered	MJ	—	—	—	—	—	—
Oil fuels - production & delivery	MJ	—	—	—	—	0.14	0.14
Oil fuels - delivered	MJ	—	—	—	—	1.00	1.00
Oil fuels - feedstock	MJ	—	—	—	—	—	—
Other fuels - production & delivery	MJ	0.04	0.20	0.11	0.21	—	—
Other fuels - delivered	MJ	1.00	1.00	1.00	1.00	—	—
Other fuels - feedstock	MJ	—	—	—	—	—	—
Total energy	MJ	1.04	1.20	1.11	1.21	1.14	1.14
Fuels							
Coal	MJ	1.02	1.10	—	1.11	—	—
Oil	MJ	0.01	0.02	—	0.01	1.09	1.09
Gas	MJ	—	0.07	1.11	0.07	0.05	0.05
Hydro	MJ	—	—	—	—	—	—
Nuclear	MJ	—	0.01	—	0.01	—	—
Lignite	MJ	—	—	—	—	—	—
Total fuels	MJ	1.03	1.20	1.11	1.21	1.14	1.14
Feedstock							
Coal	MJ	—	—	—	—	—	—
Oil	MJ	—	—	—	—	—	—
Total feedstock	MJ	—	—	—	—	—	—
Total fuels & feedstock	MJ	1.04	1.20	1.11	1.21	1.14	1.14
Raw materials							
Bauxite	mg	—	—	—	—	—	—
Brine	mg	—	—	—	—	—	—
Fe-Mn	mg	—	—	—	—	—	—
Iron ore	mg	90	117	—	98	16	16
Limestone	mg	32	41	—	34	6	6
Met coal	mg	37	48	—	40	7	7
Water	mg	82,836	690,116	136	699,800	39,080	39,080
Air emissions							
Dust	mg	478	529	80	208	14	17
CO	mg	68	79	—	12	20	20
CO2	mg	81,265	140,258	52,487	63,115	81,253	80,598
SOx	mg	1,027	1,683	14	1,222	1,451	1,297
NOx	mg	305	424	749	855	382	382
HCl	mg	20	21	—	1	—	—
HF	mg	1	1	—	—	—	—
HC	mg	18	63	474	1	149	149
Metals	mg	—	—	—	—	1	1
CH4	mg	258	362	148,670	367	3	3
Water emissions							
COD	mg	—	5	—	5	1	1
BOD	mg	—	—	—	—	1	1
Acid	mg	—	5	—	5	—	—
Metal ions	mg	—	1	—	1	—	—
Dissolved solids	mg	—	—	—	—	—	—
Suspended solids	mg	32	37	—	35	2	2
Hydrocarbons	mg	—	—	—	10	1	1
Phenol	mg	—	—	—	—	1	1
Solid waste							
Mineral waste	mg	7,132	7,725	7	7,808	51	51
Slags\ash	mg	2,037	23,088	2	3,131	9	9
Industrial waste	mg	1	2	—	2	119	119

Appendix 2 Fuels

Gross inputs and outputs associated with the production, delivery and use of fuels/MJ

Totals may not agree because of rounding errors

Input/output	Units	Fuel					
		Light fuel oil	Gas oil	Kerosine	Diesel	Gasoline	Propane
Energy							
Oil fuels - production & delivery	MJ	0.14	0.14	0.14	0.14	0.14	0.15
Oil fuels - delivered	MJ	1.00	1.00	1.00	1.00	1.00	1.00
Total energy	MJ	1.14	1.14	1.14	1.14	1.14	1.15
Fuels							
Oil	MJ	1.09	1.09	1.09	1.09	1.09	1.09
Gas	MJ	0.05	0.05	0.05	0.05	0.05	0.05
Total fuels	MJ	1.14	1.14	1.14	1.14	1.14	1.15
Feedstock		—	—	—	—	—	—
Total fuels & feedstock	MJ	1.14	1.14	1.14	1.14	1.14	1.15
Raw materials							
Iron ore	mg	16	16	16	16	16	16
Limestone	mg	6	6	6	6	6	6
Met coal	mg	7	7	7	7	7	7
Water	mg	39,080	39,080	39,080	39,080	39,080	39,157
Air emissions							
Dust	mg	14	7	7	67	67	13
CO	mg	20	20	20	703	703	703
CO2	mg	81,119	76,935	76,935	78,080	66,876	68,354
SOx	mg	1,209	390	100	227	227	47
NOx	mg	382	382	382	889	889	889
HC	mg	149	149	149	279	279	319
Lead	mg	—	—	—	—	4	—
Metals	mg	1	—	—	—	—	—
CH4	mg	3	3	3	3	3	3
Water emissions							
COD	mg	1	1	1	1	1	1
BOD	mg	1	1	1	1	1	1
Suspended solids	mg	2	2	2	2	2	2
Hydrocarbons	mg	1	1	1	1	1	1
Phenol	mg	1	1	1	1	1	1
Solid waste							
Mineral waste	mg	51	51	51	51	51	51
Slags\ash	mg	9	9	9	9	9	9
Industrial waste	mg	119	119	119	119	119	119

Appendix 3 Fuels

Gross inputs and outputs associated with the production, delivery and use of fuels/MJ

Totals may not agree because of rounding errors

Input/output	Units	Fuel			
		Butane	Lubricating oil	Grease	Grid electricity
Energy					
Electricity - production & delivery	MJ	—	—	—	2.36
Electricity - delivered	MJ	—	—	—	1.00
Oil fuels - production & delivery	MJ	0.15	0.14	0.14	—
Oil fuels - delivered	MJ	1.00	1.00	1.00	—
Total energy	MJ	1.15	1.14	1.14	3.36
Fuels					
Coal	MJ	—	—	—	2.10
Oil	MJ	1.09	1.09	1.09	0.33
Gas	MJ	0.05	0.05	0.05	0.07
Hydro	MJ	—	—	—	0.04
Nuclear	MJ	—	—	—	0.82
Total fuels	MJ	1.15	1.14	1.14	3.36
Feedstock	MJ	0.00	0.00	0.00	0.00
Total fuels & feedstock	MJ	1.15	1.14	1.14	3.36
Raw materials					
Iron ore	mg	16	16	16	157
Limestone	mg	6	6	6	62
Met coal	mg	7	7	7	65
Water	mg	39,155	39,078	39,078	197,506
Air	mg	—	—	—	9
Air emissions					
Dust	mg	13	7	7	983
CO	mg	703	3	3	140
CO2	mg	69,828	8,246	8,246	192,684
SOx	mg	47	47	47	2,543
NOx	mg	889	49	49	784
HCl	mg	—	—	—	41
HF	mg	—	—	—	2
HC	mg	319	249	149	135
CH4	mg	3	2	2	601
Water emissions					
COD	mg	1	1	1	—
BOD	mg	1	1	1	—
Acid	mg	—	—	—	5
Metal ions	mg	—	—	—	2
Suspended solids	mg	2	2	2	62
Hydrocarbons	mg	1	21	21	1
Phenol	mg	1	1	1	—
Solid waste					
Mineral waste	mg	51	51	51	14,677
Slags\ash	mg	9	9	9	4,464
Industrial waste	mg	119	119	119	37,069

Appendix 4 Transport

Gross inputs and outputs associated with road transport/vehicle km

Input/output	**Units**	**Vehicle type/payload**				
Totals may not agree because of rounding errors		**Rigid 10 - 12 t**	**Rigid 13 -21 t**	**Rigid 17.5 t concrete mixer**	**Rigid 21 t tipper**	**Articulated 18 - 24 t**
Energy						
Electricity - production & delivery	MJ	0.32	0.51	0.47	0.68	0.51
Electricity - delivered	MJ	0.14	0.22	0.20	0.29	0.22
Oil fuels - production & delivery	MJ	1.33	1.65	2.88	2.03	2.13
Oil fuels - delivered	MJ	9.02	11.00	19.59	13.63	14.40
Oil fuels - feedstock	MJ	0.18	0.42	0.37	0.50	0.39
Other fuels - production & delivery	MJ	0.05	0.06	0.06	0.08	0.06
Other fuels - delivered	MJ	0.33	0.44	0.42	0.50	0.43
Other fuels - feedstock	MJ	0.34	0.49	0.48	0.81	0.55
Total energy	MJ	11.70	14.77	24.46	18.53	18.70
Fuels						
Coal	MJ	0.56	0.74	0.76	1.19	0.84
Oil	MJ	9.79	11.86	21.23	14.71	15.58
Gas	MJ	0.74	0.85	1.28	1.03	1.03
Hydro	MJ	0.01	0.01	0.01	0.01	0.01
Nuclear	MJ	0.09	0.11	0.12	0.16	0.12
Total fuels	MJ	11.17	13.57	23.40	17.10	17.58
Feedstock						
Coal	MJ	0.33	0.46	0.45	0.78	0.52
Total feedstock	MJ	0.33	0.46	0.45	0.78	0.52
Total fuels & feedstock	MJ	11.51	14.03	23.86	17.88	18.11
Raw materials						
Barytes	mg	7	7	7	7	7
Bauxite	mg	148	205	202	347	233
Brine	mg	79	86	86	104	90
Fe-Mn	mg	84	116	115	197	132
Fluorspar	mg	3	4	4	6	4
Iron ore	mg	25,646	35,467	349,934	60,053	40,376
Lead	mg	73	74	74	74	74
Limestone	mg	9,071	12,544	12,377	21,239	14,280
Met coal	mg	10,549	14,589	14,394	24,703	16,609
Water	mg	716,490	926,263	1,254,100	1,367,600	1,126,700
Air	mg	1,672	2,242	2,214	3,668	2,526
Sulphur	mg	110	148	146	241	166
Air emissions						
Dust	mg	804	990	1,566	1,314	1,249
CO	mg	6,289	7,628	13,681	9,465	10,028
CO2	mg	736,100	892,751	1,564,300	1,116,400	1,163,100
SOx	mg	4,296	5,566	7,464	8,261	6,755
NOx	mg	8,290	10,044	17,692	12,517	13,108
HCl	mg	4	6	6	8	6
F	mg	1	1	1	2	1
HC	mg	2,652	3,200	5,598	3,970	4,160
CH4	mg	541	614	631	791	656
Water emissions						
COD	mg	10	12	22	15	16
BOD	mg	9	11	20	14	14
Acid	mg	5	7	7	12	8
Metal ions	mg	1	2	2	3	2
Suspended solids	mg	3,307	4,572	4,512	7,740	5,205
Hydrocarbons	mg	10	12	20	14	15
Phenol	mg	9	11	20	14	14
Solid waste						
Plastics	mg	7	7	7	7	7
Organics	mg	4	4	4	4	4
Mineral waste	mg	38,811	53,453	52,980	90,052	60,834
Slags\ash	mg	2,150	2,905	2,940	4,780	3,303
Industrial waste	mg	1,070	1,297	2,321	1,609	1,703

Appendix 5 Transport

Gross inputs and outputs associated with waterborne transport/tonne km

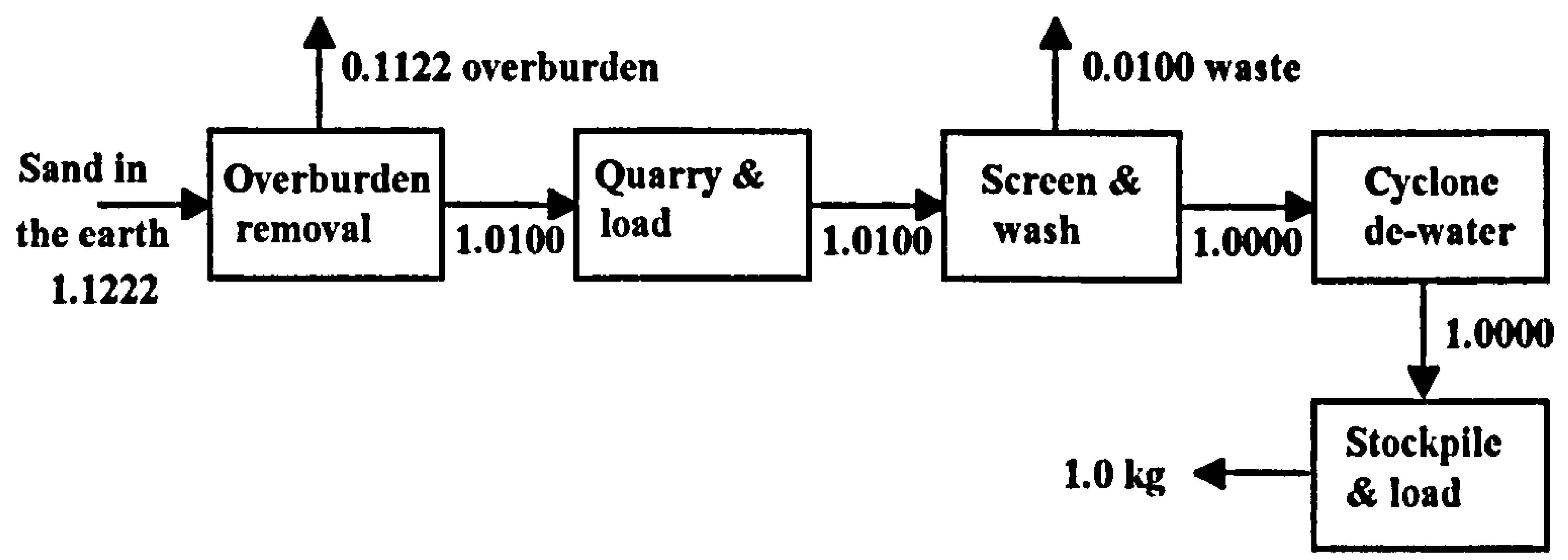
Input/output	Units	Craft type/deadweight tonnage				
Totals may not agree because of rounding errors		**Oil tanker 65,000 t 13 knots**	**Oil tanker 100,000 t 13 knots**	**Oil tanker 250,000 t 13 knots**	**'Average' bulk carrier 100,000 t 18.5 knots**	**Coal barge (inland canal) 500 t**
Energy						
Oil fuels - production & delivery	MJ	0.01	—	—	0.01	0.05
Oil fuels - delivered	MJ	0.04	0.03	0.02	0.05	0.31
Total energy	MJ	0.05	0.03	0.02	0.06	0.37
Fuels						
Coal	MJ	—	—	—	—	0.01
Oil	MJ	0.04	0.03	0.02	0.06	0.34
Gas	MJ	—	—	—	—	0.02
Total fuels	MJ	0.05	0.03	0.02	0.06	0.37
Feedstock						
Coal	MJ	—	—	—	—	0.01
Total feedstock	MJ	—	—	—	—	0.01
Total fuels & feedstock	MJ	0.05	0.04	0.02	0.06	0.38
Raw materials						
Bauxite	mg	—	—	—	—	4
Fe-Mn	mg	—	—	—	—	2
Iron ore	mg	66	56	42	40	655
Limestone	mg	23	20	15	14	232
Met coal	mg	27	23	17	16	270
Water	mg	2,439	1,917	1,304	2,681	21,289
Air	mg	4	3	2	2	38
Sulphur	mg	—	—	—	—	3
Air emissions						
Dust	mg	1	1	1	1	25
CO	mg	1	1	—	1	221
CO2	mg	3,241	2,437	1,542	4,488	25,100
SOx	mg	62	47	30	83	127
NOx	mg	15	12	7	21	284
HC	mg	6	4	3	8	89
CH4	mg	1	—	—	—	5
Water emissions						
Suspended solids	mg	9	7	5	5	84
Solid waste						
Mineral waste	mg	99	84	63	61	982
Slags\ash	mg	5	4	3	3	52
Industrial waste	mg	5	4	2	7	37

Appendix 6 Transport

Gross inputs and outputs associated with rail freight transport/tonne km

Input/output	Units	Rail type	
Totals may not agree because of rounding errors		**Network average - diesel & electric**	**Circuit working diesel**
Energy			
Electricity - production & delivery	MJ	0.11	0.04
Electricity - delivered	MJ	0.05	0.02
Oil fuels - production & delivery	MJ	0.06	0.02
Oil fuels - delivered	MJ	0.43	0.15
Other fuels - delivered	MJ	0.02	0.01
Other fuels - feedstock	MJ	0.01	—
Total energy	MJ	0.68	0.24
Fuels			
Coal	MJ	0.11	0.04
Oil	MJ	0.48	0.17
Gas	MJ	0.04	0.02
Nuclear	MJ	0.04	0.01
Total fuels	MJ	0.68	0.24
Feedstock			
Coal	MJ	0.01	—
Total feedstock	MJ	0.01	
Total fuels & feedstock	MJ	0.69	0.25
Raw materials			
Bauxite	mg	6	1
CaSO4	mg	19	4
Fe-Mn	mg	3	—
Iron ore	mg	1,016	254
Limestone	mg	5,179	1,166
Met coal	mg	418	105
Sand	mg	620	139
Water	mg	42,571	13,097
Shale	mg	53	12
Air	mg	54	15
Sulphur	mg	4	—
Air emissions			
Dust	mg	56	19
CO	mg	17	6
CO2	mg	43,498	15,578
SOx	mg	369	121
NOx	mg	217	81
HCl	mg	2	1
HC	mg	79	31
CH4	mg	56	29
Water emissions			
COD	mg	1	—
Suspended solids	mg	135	34
Solid waste			
Mineral waste	mg	2,250	617
Slags\ash	mg	276	86
Industrial waste	mg	597	140

Production and bulk road delivery of building sand



Schematic flow diagram for the production of building sand from sandpits
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of building sand/kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.05
Electricity - delivered	0.02
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.04
Total energy	0.11

Primary fuels	MJ
Coal	0.04
Oil	0.05
Nuclear	0.02
Total fuels	0.11
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	0.11

Raw materials	mg
Iron ore	76
Limestone	27
Met coal	31
Sand	1,000,000
Water	4,006,300
Air	5

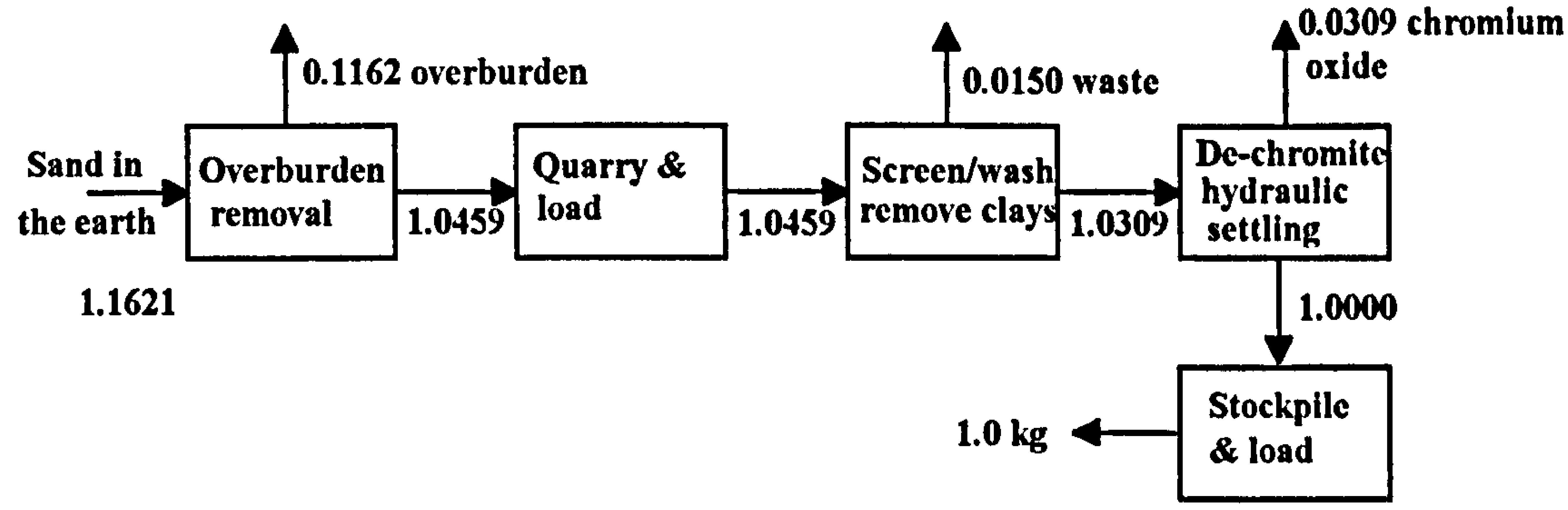
Water emissions	mg
Suspended solids	11

Solid waste	mg
Mineral waste	122,622
Slags/ash	94
Industrial waste	5

Air emissions	mg
Dust	22
CO	19
CO_2	6,671
SO_x	67
NO_x	41
HCl	1
HC	11
CH_4	13

Packaging & delivery: Bulk delivery - no packaging
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 48 km

Production and bulk road delivery of flat glass sand



Schematic flow diagram for the production of flat glass sand from sandpits
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of flat glass sand/kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.07
Electricity - delivered	0.03
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.04
Total energy	0.14

Primary fuels	MJ
Coal	0.06
Oil	0.05
Nuclear	0.02
Total fuels	0.14
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	0.14

Raw materials	mg
Iron ore	79
Limestone	28
Met coal	33
Sand	1,000,000
Water	4,008,100
Air	5

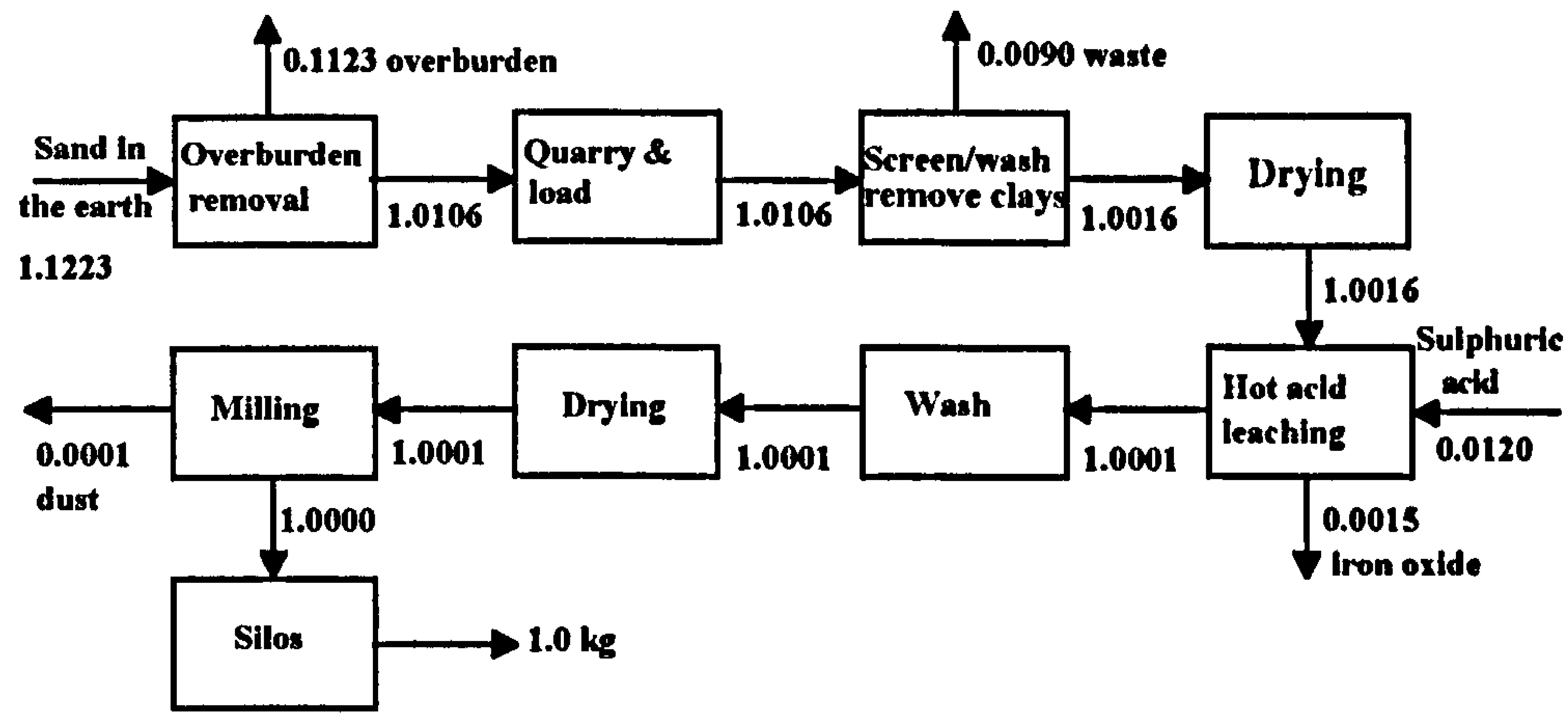
Water emissions	mg
Suspended solids	11

Solid waste	mg
Mineral waste	162,668
Slags/ash	132
Industrial waste	5

Air emissions	mg
Dust	30
CO	20
CO_2	8,354
SO_x	89
NO_x	48
HCl	1
HC	13
CH_4	18

Packaging & delivery: Bulk delivery - no packaging
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 48 km

Production and bulk road delivery of fibre glass sand



Schematic flow diagram for the production of fibre glass sand from sandpits
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of fibre glass sand /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	1.12
Electricity - delivered	0.47
Oil fuels - production & delivery	0.10
Oil fuels - delivered	0.72
Other fuels - production & delivery	0.01
Other fuels - delivered	0.09
Other fuels - feedstock	0.01
Total energy	2.53

Primary fuels	MJ
Coal	1.00
Oil	0.94
Gas	0.18
Hydro	0.02
Nuclear	0.39
Sulphur	0.04
Recovered	-0.04
Total fuels	2.52
Primary feedstocks	**MJ**
Total feedstocks	0.01
Total fuels & feedstocks	2.53

Raw materials	mg
Bauxite	1
Brine	4
Clay	8
Iron ore	184
Limestone	20,339
Met coal	76
Sand	1,000,000
Water	8,324,500
Wood	320
Nitrogen	2
Air	60,529
Sulphur	3,985

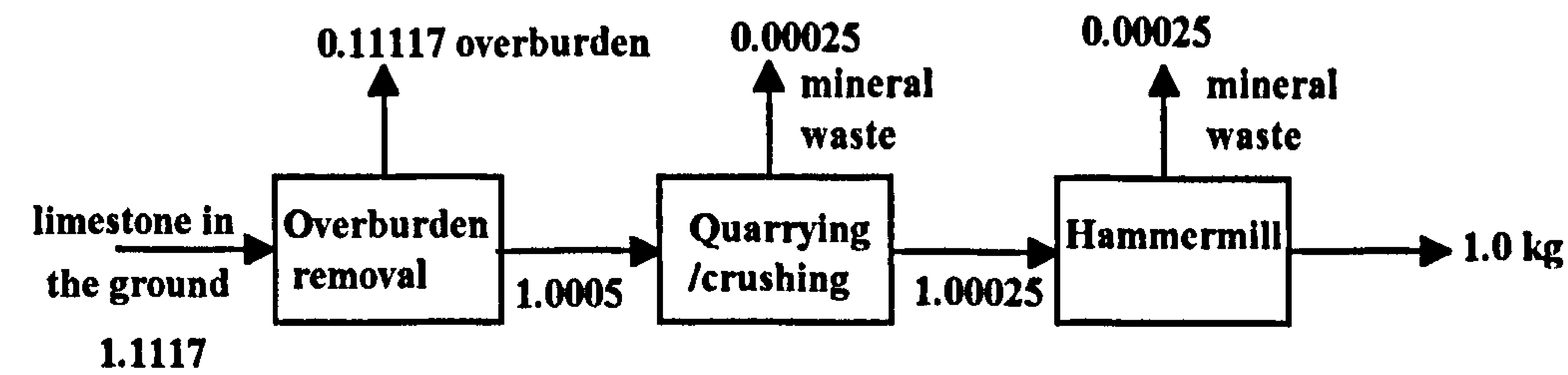
Water emissions	mg
COD	2
BOD	1
Acid	3
Metals	1
Suspended solids	17
HC	1
Phenol	1

Air emissions	mg
Dust	610
CO	326
CO_2	160,886
SO_x	1,618
NO_x	733
HCl	20
HF	1
HC	220
CH_4	427

Solid waste	mg
Paper	63
Metals	6
Other ref	115
Mineral waste	128,500
Slags/ash	2,131
Industrial waste	2,358

Packaging & delivery: Bulk delivery - no packaging
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 48 km

Production and bulk road delivery of limestone



Schematic flow diagram for the extraction and processing of limestone
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of limestone/kg
Totals may not agree because of rounding errors

Energy	**MJ**
Electricity - production & delivery	0.05
Electricity - delivered	0.02
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.07
Total energy	0.16

Primary fuels	**MJ**
Coal	0.05
Oil	0.08
Gas	0.01
Nuclear	0.02
Total fuels	0.16
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	0.16

Raw materials	**mg**
Bauxite	1
Iron ore	180
Limestone	1,000,100
Met coal	74
Water	9,456
Air	11

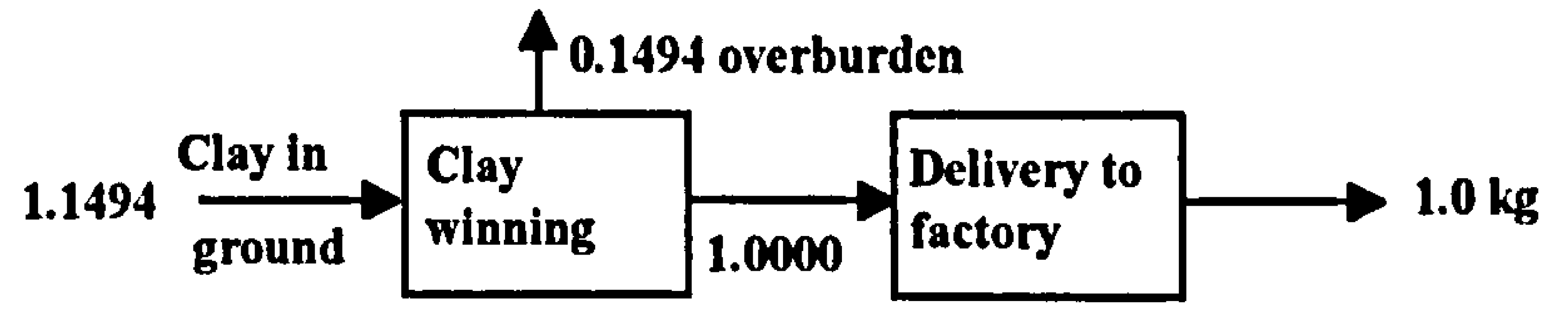
Water emissions	**mg**
Suspended solids	24

Solid waste	**mg**
Mineral waste	1,093
Slags/ash	111
Industrial waste	111,177

Air emissions	**mg**
Dust	32
CO	51
CO_2	9,761
SO_x	86
NO_x	80
HCl	1
HC	23
CH_4	16

Packaging & delivery: Bulk delivery - no packaging
Road transport: articulated vehicle, 25 tonne payload, returning empty, return distance 129 km

Clay winning and on-site delivery - roof tile manufacture



Schematic flow diagram for the winning of clay used in clay roof tile production
All flows are in kg

Gross inputs and outputs associated with clay winning - roof tile manufacture/kg
Totals may not agree because of rounding errors

Energy	MJ
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.04
Total energy	0.05

Primary fuels	MJ
Oil	0.05
Total fuels	0.05
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	0.05

Raw materials	mg
Clay	1,000,000
Water	1,732

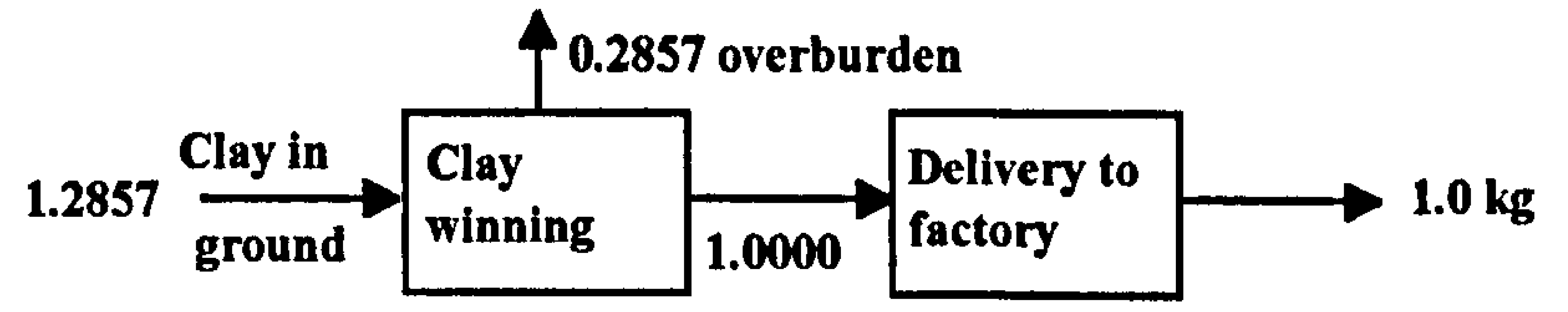
Water emissions	mg
Negligible	

Air emissions	mg
CO	1
CO_2	3,477
SO_x	34
NO_x	17
HC	7

Solid waste	mg
Mineral waste	149,402
Industrial waste	5

Packaging & delivery: Bulk delivery - no packaging
Internal transport

Clay winning and on-site delivery - clay brick manufacture



Schematic flow diagram for the winning of clay used in brick production
All flows are in kg

Gross inputs and outputs associated with clay winning - clay brick manufacture/kg
Totals may not agree because of rounding errors

Energy	**MJ**
Oil fuels - delivered	0.02
Total energy	0.02

Primary fuels	**MJ**
Oil	0.02
Total fuels	0.02
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	0.02

Raw materials	**mg**
Clay	1,000,000
Water	814

Water emissions	**mg**
Negligible	

Air emissions	**mg**
CO_2	1,602
SO_x	8
NO_x	8
HC	3

Solid waste	**mg**
Mineral waste	285,701
Industrial waste	2

Packaging & delivery: Bulk delivery - no packaging
Internal transport

Production and bulk road delivery of gypsum[47]

1.0000 Gypsum in the ground → **Gypsum mining** → 1.0000 → **Crushing & grinding** → 1.0 kg

Schematic flow diagram for the extraction and processing of gypsum
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of gypsum /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.36
Electricity - delivered	0.15
Oil fuels - production & delivery	0.03
Oil fuels - delivered	0.22
Oil fuels - feedstock	0.01
Other fuels - delivered	0.01
Other fuels - feedstock	0.01
Total energy	0.79

Primary fuels	MJ
Coal	0.33
Oil	0.29
Gas	0.03
Hydro	0.01
Nuclear	0.13
Total fuels	0.77
Primary feedstocks	**MJ**
Coal	0.01
Total feedstocks	0.01
Total fuels & feedstocks	0.78

Raw materials	mg
Bauxite	3
Brine	1
Gypsum	1,000,000
Fe-Mn	2
Iron ore	576
Lead	1
Limestone	205
Met coal	237
Water	46,018
Air	36
Sulphur	2

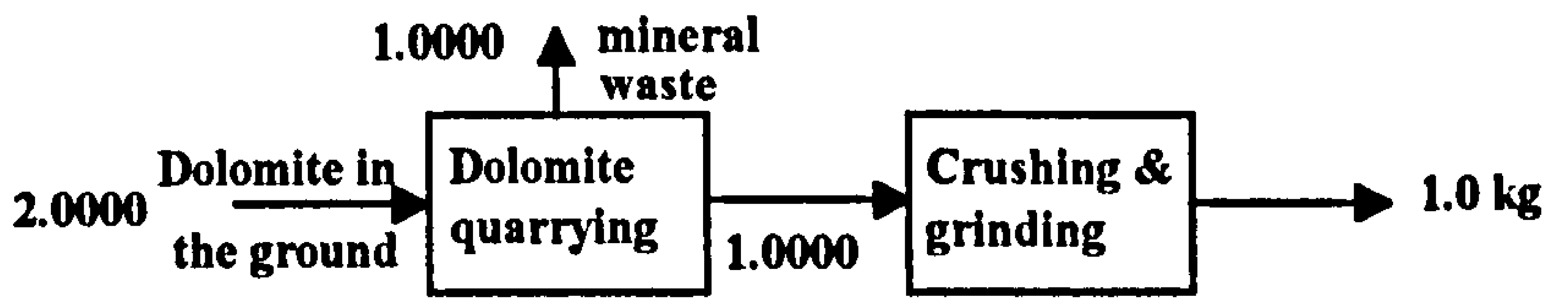
Water emissions	mg
Suspended solids	94,581

Solid waste	mg
Mineral waste	3,049
Slags/ash	719
Industrial waste	31

Air emissions	mg
Dust	166
CO	159
CO_2	46,617
SO_x	502
NO_x	305
HCl	6
HC	80
CH_4	100

Packaging & delivery: Bulk delivery - no packaging
Road transport: articulated vehicle, 25 tonne payload, returning empty, notional return distance 200 km

Production and bulk road delivery of dolomite[47]



Schematic flow diagram for the extraction and processing of dolomite
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of dolomite /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.11
Electricity - delivered	0.05
Oil fuels - production & delivery	0.02
Oil fuels - delivered	0.12
Total energy	0.30

Primary fuels	MJ
Coal	0.10
Oil	0.14
Gas	0.01
Nuclear	0.04
Total fuels	0.29
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	0.30

Raw materials	mg
Bauxite	2
Iron ore	284
Limestone	101
Met coal	117
Water	1,067,400
Dolomite	1,000,000
Air	18
Sulphur	1

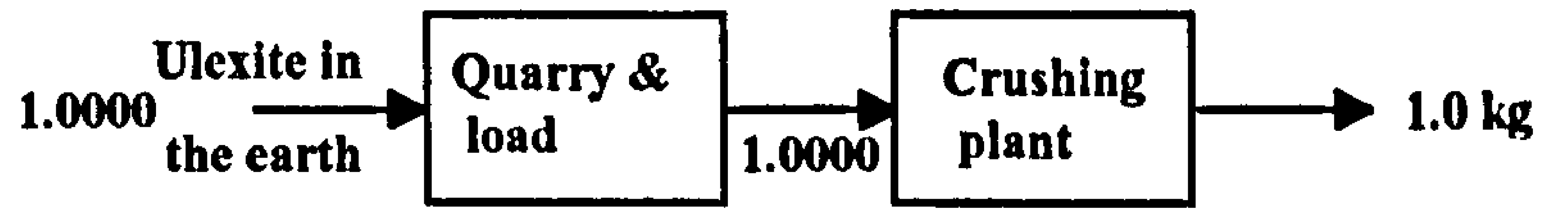
Water emissions	mg
Suspended solids	38

Solid waste	mg
Mineral waste	1,001,100
Slags/ash	224
Industrial waste	16

Air emissions	mg
Dust	53
CO	75
CO_2	18,268
SO_x	187
NO_x	133
HCl	2
HC	38
CH_4	32

Packaging & delivery: Bulk delivery - no packaging
Road transport: articulated vehicle, 25 tonne payload, returning empty, notional return distance 200 km

Production and bulk delivery of ulexite[47]



Schematic flow diagram for the production and delivery of ulexite
All flows are in kg

Gross inputs and outputs associated with the production and delivery of ulexite/kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.13
Electricity - delivered	0.05
Oil fuels - production & delivery	0.04
Oil fuels - delivered	0.29
Oil fuels - feedstock	0.01
Other fuels - delivered	0.01
Other fuels - feedstock	0.01
Total energy	0.54

Primary fuels	MJ
Coal	0.12
Oil	0.33
Gas	0.02
Nuclear	0.04
Total fuels	0.52
Primary feedstocks	**MJ**
Coal	0.01
Total feedstocks	0.01
Total fuels & feedstocks	0.53

Raw materials	mg
Bauxite	4
Brine	2
Fe-Mn	2
Iron ore	699
Lead	1
Limestone	248
Met coal	288
Water	1,131,000
Ulexite	1,000,000
Air	44
Sulphur	3

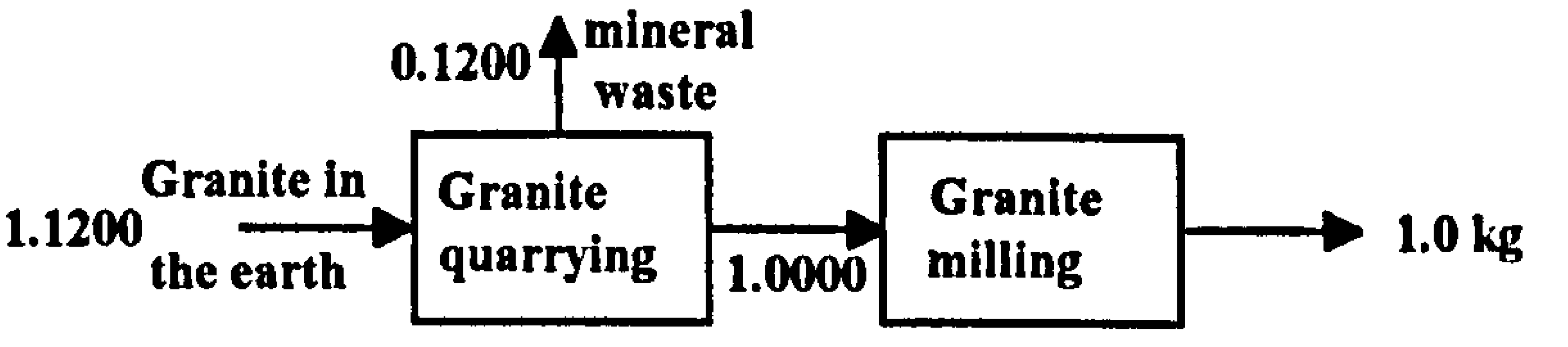
Water emissions	mg
Suspended solids	10

Solid waste	mg
Mineral waste	1,780
Slags/ash	281
Industrial waste	36

Air emissions	mg
Dust	174
CO	210
CO_2	33,086
SO_x	254
NO_x	304
HCl	2
HC	90
CH_4	42

Packaging & delivery: Bulk delivery - no packaging
Road transport: Articulated vehicles, 24 tonne payload, returning empty, notional return distance 483 km

Production and bulk road delivery of milled granite[47]



Schematic flow diagram for the production and delivery of milled granite
All flows are in kg

Gross inputs and outputs associated with the production and delivery of milled granite/kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.68
Electricity - delivered	0.29
Oil fuels - production & delivery	0.08
Oil fuels - delivered	0.57
Oil fuels - feedstock	0.01
Other fuels - delivered	0.01
Other fuels - feedstock	0.01
Total energy	1.66

Primary fuels	MJ
Coal	0.61
Oil	0.72
Gas	0.06
Hydro	0.01
Nuclear	0.24
Total fuels	1.64
Primary feedstocks	**MJ**
Coal	0.01
Total feedstocks	0.01
Total fuels & feedstocks	1.65

Raw materials	mg
Bauxite	20
Brine	4
Fe-Mn	2
Iron ore	741
Lead	1
Limestone	264
Met coal	305
Water	240,961
Granite	1,000,000
Air	48
Sulphur	3

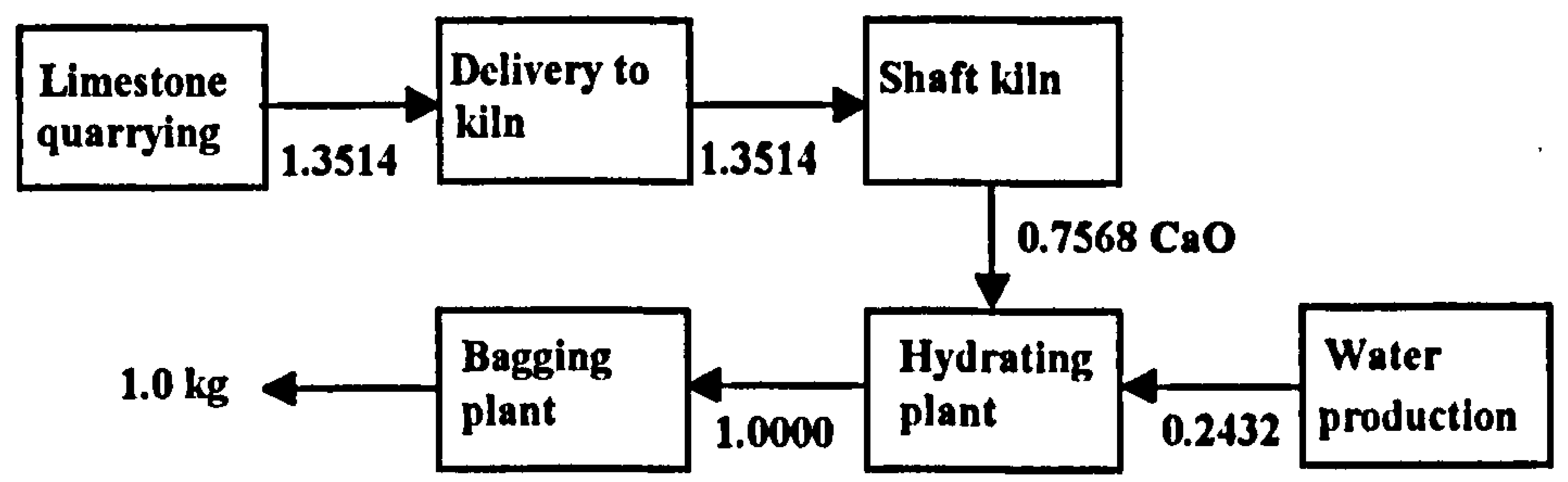
Water emissions	mg
COD	1
BOD	1
Acid	2
Metals	1
Suspended solids	9,109
HC	1
Phenol	1

Solid waste	mg
Mineral waste	125,270
Slags /ash	1,334
Industrial waste	79

Air emissions	mg
Dust	1,081
CO	432
CO_2	100,653
SO_x	919
NO_x	743
HCl	12
HF	1
HC	199
CH_4	184

Packaging & delivery: Bulk delivery - no packaging
Road transport: Articulated vehicle, 24 tonne payload, returning empty, notional return distance 483 km

Production and road delivery of bagged hydrated lime



Schematic flow diagram for the production of bagged hydrated lime
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of bagged hydrated lime /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.59
Electricity - delivered	0.25
Oil fuels - production & delivery	0.05
Oil fuels - delivered	0.32
Oil fuels - feedstock	0.01
Other fuels - production & delivery	0.50
Other fuels - delivered	4.42
Other fuels - feedstock	0.27
Total energy	6.40

Primary fuels	MJ
Coal	0.53
Oil	0.42
Gas	4.94
Hydro	0.01
Nuclear	0.21
Total fuels	6.11
Primary feedstocks	**MJ**
Coal	0.02
Wood	0.11
Total feedstock	0.13
Total fuels & feedstock	6.23

Raw materials	mg
Bauxite	9
Brine	235
Clay	557
Fe-Mn	5
Iron ore	1,435
Lead	2
Limestone	1,351,900
Met coal	590
Water	683,386
Wood	21,348
Air	444
Sulphur	29

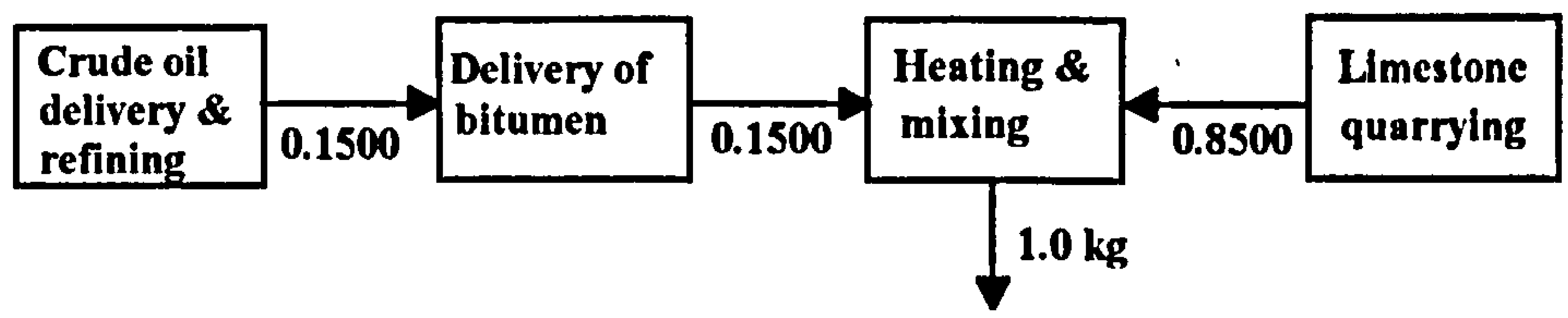
Water emissions	mg
COD	60
BOD	6
Acid	2
Metals	1
Suspended solids	260
HC	1
Other N	1

Air emissions	mg
Dust	1,871
CO	15,246
CO_2	898,801
SO_x	8,916
NO_x	3,775
HCl	10
HF	1
HC	2,217
CH_4	6,722

Solid waste	mg
Plastic containers	3
Paper	4,214
Plastics	27
Metals	373
Other ref	7,635
Mineral waste	6,813
Slags/ash	1,203
Industrial waste	150,274

Packaging & delivery: Packaging in 180 g paper bags on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 600 km

Production and road delivery of block form mastic asphalt - Grade II type F1076, suitable for domestic floors



Schematic flow diagram for the production of block form mastic asphalt
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of block form mastic asphalt (notional unit inputs and outputs)/kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.08
Electricity - delivered	0.03
Oil fuels - production & delivery	0.98
Oil fuels - delivered	0.54
Oil fuels - feedstock	6.41
Other fuels - delivered	0.01
Other fuels - feedstock	0.16
Total energy	8.21

Primary fuels	MJ
Coal	0.10
Oil	1.14
Gas	0.35
Nuclear	0.03
Total fuels	1.63
Primary feedstocks	**MJ**
Coal	0.02
Oil	6.40
Wood	0.14
Total feedstock	6.56
Total fuels & feedstock	8.20

Raw materials	mg
Bauxite	7
Brine	2
Fe-Mn	4
Iron ore	1,183
Lead	2
Limestone	850,379
Met coal	486
Water	170,959
Wood	9,450
Air	45
Sulphur	3

Water emissions	mg
COD	8
BOD	7
Suspended solids	150
HC	7
Phenol	7

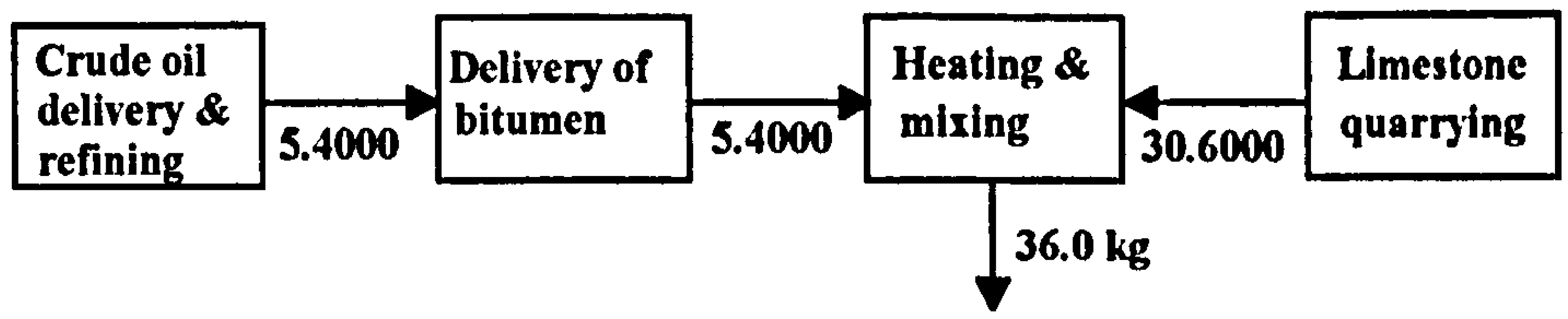
Air emissions	mg
Dust	100
CO	169
CO_2	99,466
SO_x	634
NO_x	644
HCl	2
HC	425
CH_4	44

Solid waste	mg
Paper	1
Plastics	18
Metals	370
Other ref	7,635
Mineral waste	2,740
Slags/ash	270
Industrial waste	95,318

Packaging & delivery: No packaging - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 322 km

Appendix 19 Limestone products

Production, road delivery & laying of mastic asphalt floor - 15 mm deep- Grade II type F1076



Schematic flow diagram for the production of block form mastic asphalt
All flows are in kg/square metre

Gross inputs and outputs associated with the production, road delivery & laying of mastic asphalt floor - 15 mm deep (notional inputs and outputs)/kg per square metre

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	2.76
Electricity - delivered	1.17
Oil fuels - production & delivery	36.86
Oil fuels - delivered	31.04
Oil fuels - feedstock	230.82
Other fuels - production & delivery	0.05
Other fuels - delivered	0.35
Other fuels - feedstock	5.67
Total energy	308.71

Primary fuels	MJ
Coal	3.65
Oil	53.74
Gas	13.33
Hydro	0.07
Nuclear	1.30
Total fuels	72.08
Primary feedstocks	**MJ**
Coal	0.55
Oil	230.56
Wood	5.13
Total feedstock	236.24
Total fuels & feedstock	308.32

Raw materials	mg
Barytes	4
Bauxite	263
Brine	74
Clay	6
Fe-Mn	149
Fluorspar	5
Iron ore	42,766
Lead	57
Limestone	30,613,700
Met coal	17,574
Sand	1
Water	6,607,300
Wood	340
Zinc	10
Air	1,625
Sulphur	107

Water emissions	mg
COD	293
BOD	263
Acid	16
Metals	5
Suspended solids	5,441
HC	264
Phenol	263

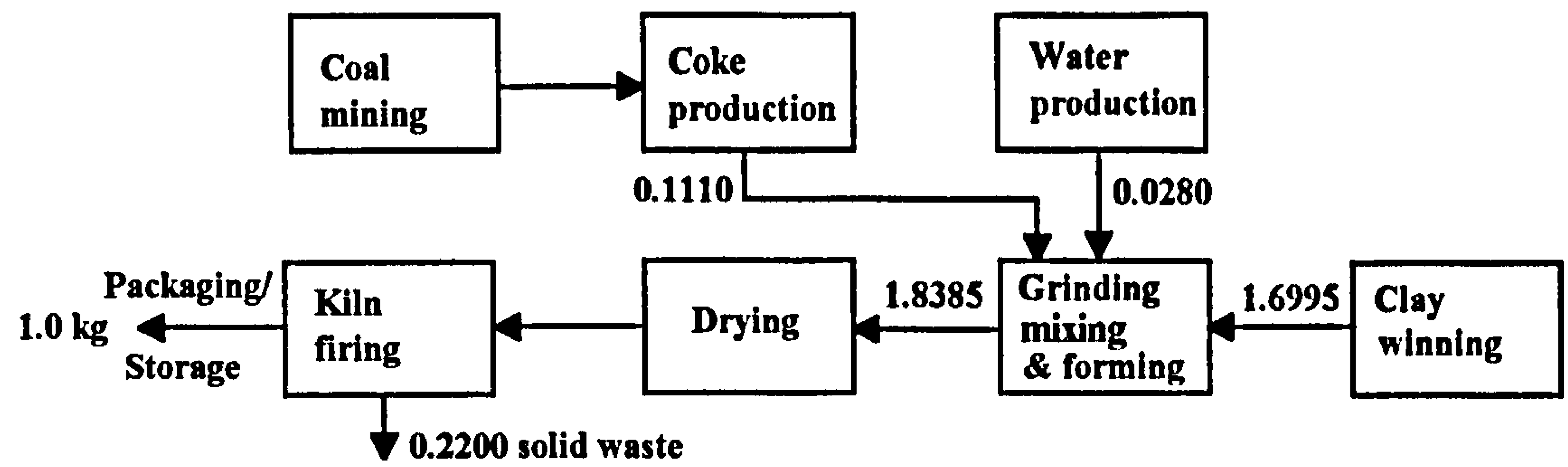
Air emissions	mg
Dust	3,700
CO	6,319
CO_2	4,472,300
SO_x	27,329
NO_x	27,594
HCl	65
F	1
HF	3
HC	17,014
Metals	1
CH_4	1,614

Solid waste	mg
Paper	48
Plastics	632
Metals	13,334
Organics	3
Other ref	274,857
Mineral waste	99,165
Slags/ash	9,827
Industrial waste	3,432,800

Packaging & delivery: No packaging - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 322 km

Appendix 20 Structural clay products

Production & road delivery of clay facing bricks



Schematic flow diagram for the production of clay facing bricks
All flows are in kg

Gross inputs and outputs associated with the production & road delivery of clay facing bricks /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.42
Electricity - delivered	0.18
Oil fuels - production & delivery	0.05
Oil fuels - delivered	0.35
Oil fuels - feedstock	0.02
Other fuels - production & delivery	0.45
Other fuels - delivered	3.25
Other fuels - feedstock	0.18
Total energy	4.90

Primary fuels	MJ
Coal	1.46
Oil	0.46
Gas	2.61
Hydro	0.01
Nuclear	0.16
Total fuels	4.71
Primary feedstocks	**MJ**
Coal	0.03
Oil	0.01
Wood	0.14
Total feedstock	0.18
Total fuels & feedstock	4.89

Raw materials	mg
Bauxite	17
Brine	4
Clay	1,699,500
Fe-Mn	10
Iron ore	2,688
Lead	2
Limestone	822
Met coal	1,104
Water	789,998
Wood	9,451
Air	72
Sulphur	5

Water emissions	mg
COD	5
Acid	6
Metals	2
Suspended solids	363
HC	1

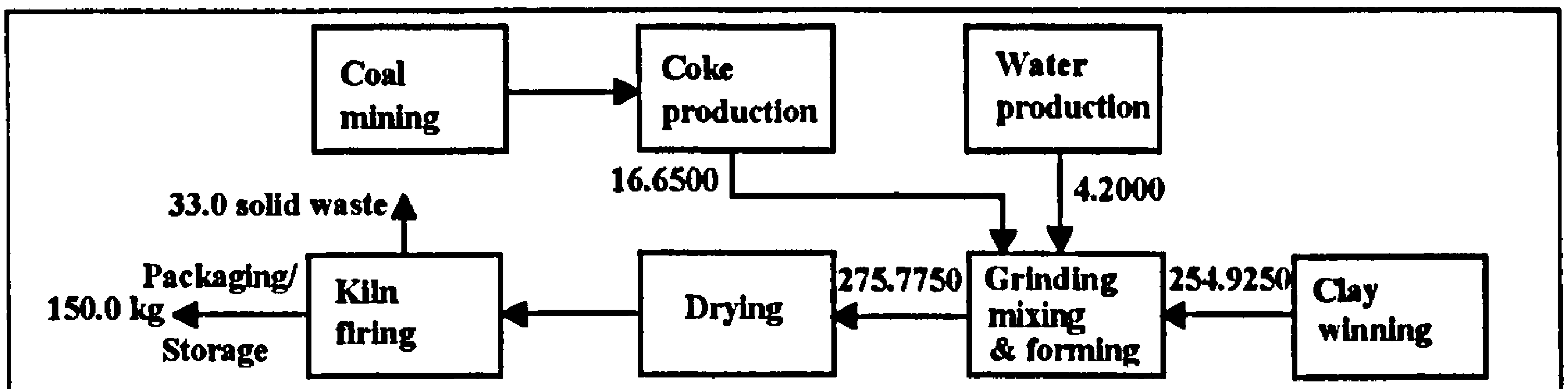
Air emissions	mg
Dust	1,022
CO	320
CO_2	387,122
SO_x	2,471
NO_x	2,552
HCl	139
HF	43
HC	1,260
CH_4	3,839

Solid waste	mg
Paper	2
Plastics	176
Metals	1,218
Other ref	7,635
Mineral waste	499,297
Slags/ash	23,578
Industrial waste	51
Fired clay	220,000
Unregulated chemicals	1

Packaging & delivery: Steel and polypropylene strapping - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 644 km

Appendix 21 Structural clay products

Production & road delivery of clay facing bricks - 65 mm



Schematic flow diagram for the production of clay facing bricks
All flows are in kg/sq m single leaf wall

Gross inputs and outputs associated with the production & road delivery of 65 mm clay facing bricks /kg per square metre single leaf wall Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	63.42
Electricity - delivered	26.87
Oil fuels - production & delivery	7.95
Oil fuels - delivered	52.40
Oil fuels - feedstock	2.78
Other fuels - production & delivery	67.51
Other fuels - delivered	487.84
Other fuels - feedstock	26.63
Total energy	735.41

Primary fuels	MJ
Coal	219.01
Oil	69.60
Gas	392.01
Hydro	1.18
Nuclear	23.97
Lignite	0.01
Total fuels	705.79
Primary feedstocks	**MJ**
Coal	5.19
Oil	1.06
Gas	0.23
Wood	21.37
Total feedstock	27.85
Total fuels & feedstock	733.64

Raw materials	mg
Barytes	29
Bauxite	2,554
Brine	588
Clay	254,925,000
Fe-Mn	1,443
Fluorspar	46
Iron ore	403,146
Lead	357
Limestone	123,276
Met coal	165,583
Sand	25
Water	118,499,600
Wood	1,417,600
Zinc	45
Shale	2
NaCl	117
Air	10,776
Sulphur	709

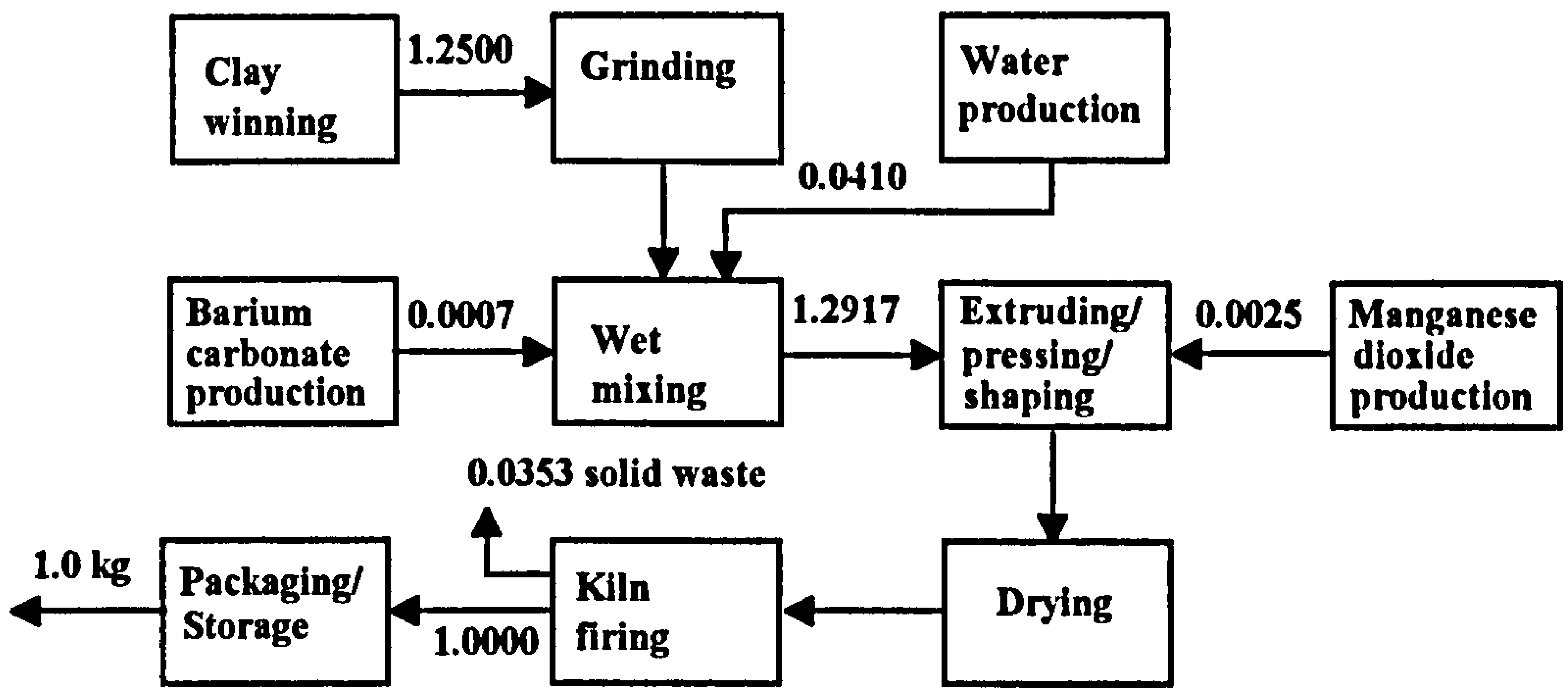
Water emissions	mg
COD	822
BOD	65
Acid	891
Metals	236
Cl^-	19
F^-	1
Dissolved organics	1
Suspended solids	54,423
Detergent/oil	1
HC	83
Phenol	63
Dissolved solids	5
Other organics	6

Air emissions	mg
Dust	153,341
CO	47,923
CO_2	58,068,300
SO_x	370,692
NO_x	382,753
HCl	20,922
F	10
HF	6,474
HC	189,030
Metals	9
CH_4	575,856

Solid waste	mg
Paper	226
Plastics	26,342
Metals	182,673
Organics	17
Other ref	1,145,200
Mineral waste	74,894,500
Slags/ash	3,536,700
Industrial waste	7,671
Fired clay	33,000,000
Unregulated chemiclas	188

Packaging & delivery: Steel and polypropylene strapping - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, notional return distance 644 km

Production and road delivery of clay roof tiles



Schematic flow diagram for the production of clay roof tiles
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of clay roof tiles /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.89
Electricity - delivered	0.38
Oil fuels - production & delivery	0.03
Oil fuels - delivered	0.18
Oil fuels - feedstock	0.01
Other fuels - production & delivery	0.26
Other fuels - delivered	2.28
Other fuels - feedstock	0.17
Total energy	4.19

Raw materials	mg
Barytes	1,066
Bauxite	12
Brine	343
Clay	1,250,000
Fe-Mn	7
Iron ore	1,874
Limestone	766
Met coal	769
Water	168,802
Wood	9,488
Pyrolusite	2,460
Air	22
Sulphur	1

Air emissions	mg
Dust	569
CO	114
CO_2	250,076
SO_x	1,337
NO_x	2,113
HCl	16
HF	244
HC	1,172
CH_4	3,605

Primary fuels	MJ
Coal	0.80
Oil	0.33
Gas	2.56
Hydro	0.01
Nuclear	0.31
Total fuels	4.01
Primary feedstocks	**MJ**
Coal	0.02
Oil	0.01
Wood	0.14
Total feedstocks	0.18
Total fuels & feedstocks	4.19

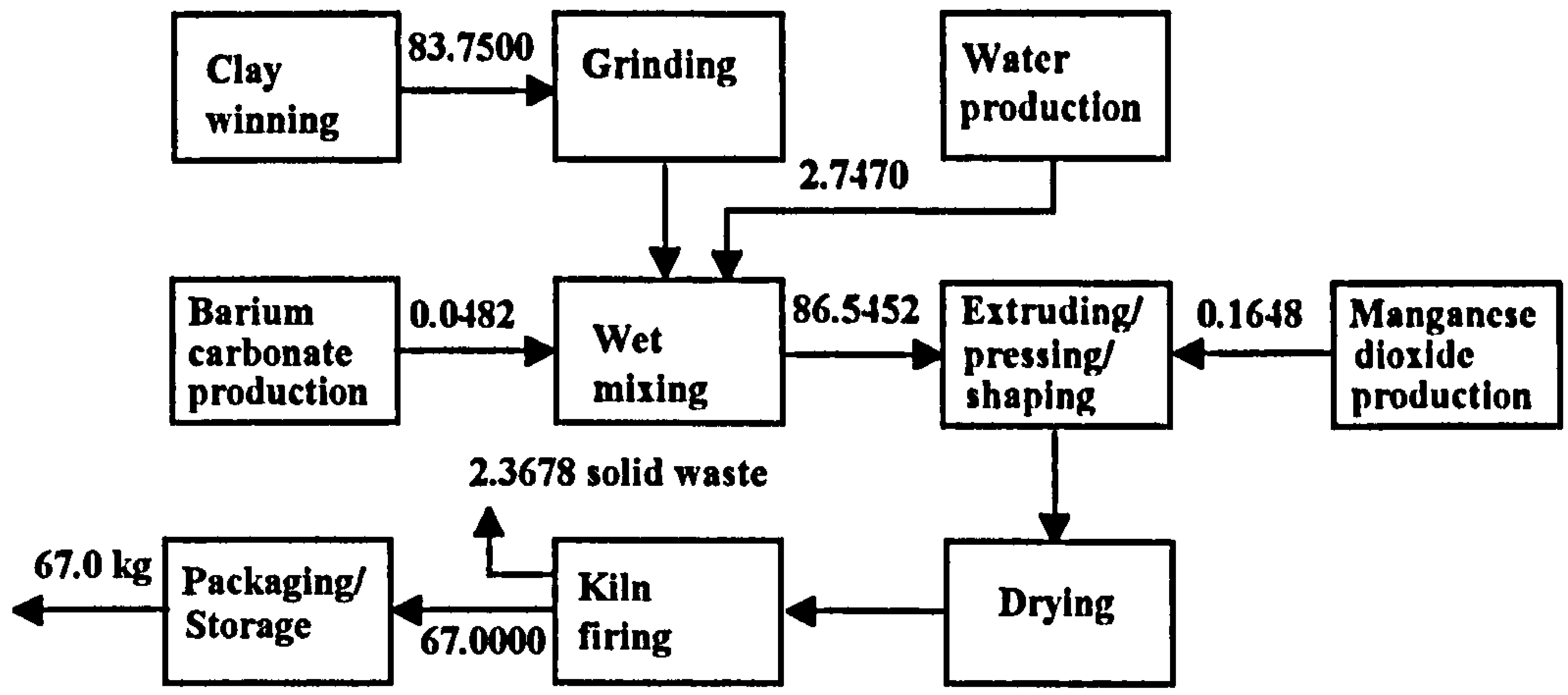
Water emissions	mg
COD	1
Acid	2
Metals	1
Suspended solids	368

Solid waste	mg
Paper	15
Plastics	175
Metals	1,219
Other ref	7,635
Mineral waste	195,075
Slags/ash	1,931
Industrial waste	37
Fired clay	35,340
Unregulated chemicals	8

Packaging & delivery: Steel and polypropylene strapping - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, return distance 155 km

Appendix 23 Structural clay products

Production and road delivery of clay roof tiles/sq metre - 60 tiles



Schematic flow diagram for the production of clay roof tiles - All flows are in kg/sq m

Gross inputs and outputs associated with the production and road delivery of clay roof tiles /kg per sq m (60 tiles)

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	59.69
Electricity - delivered	25.27
Oil fuels - production & delivery	1.84
Oil fuels - delivered	12.09
Oil fuels - feedstock	0.66
Other fuels - production & delivery	17.24
Other fuels - delivered	152.45
Other fuels - feedstock	11.24
Total energy	280.47

Raw materials	mg
Barytes	71,401
Bauxite	826
Brine	22,992
Clay	83,750,100
Fe-Mn	466
Fluorspar	15
Iron ore	125,573
Lead	55
Limestone	51,327
Met coal	51,543
Sand	22
Water	11,309,700
Wood	635,718
Zinc	20
Shale	2
Pyrolusite	164,820
NaCl	52
Air	1,472
Sulphur	97

Air emissions	mg
Dust	38,129
CO	7,643
CO_2	16,755,100
SO_x	89,574
NO_x	141,560
HCl	1,052
F	3
HF	16,333
HC	78,499
Metals	11
CH_4	241,555

Primary fuels	MJ
Coal	53.68
Oil	22.21
Gas	171.29
Hydro	1.00
Nuclear	20.76
Total fuels	268.95
Primary feedstocks	**MJ**
Coal	1.61
Oil	0.47
Gas	0.10
Wood	9.57
Total feedstocks	11.76
Total fuels & feedstocks	280.70

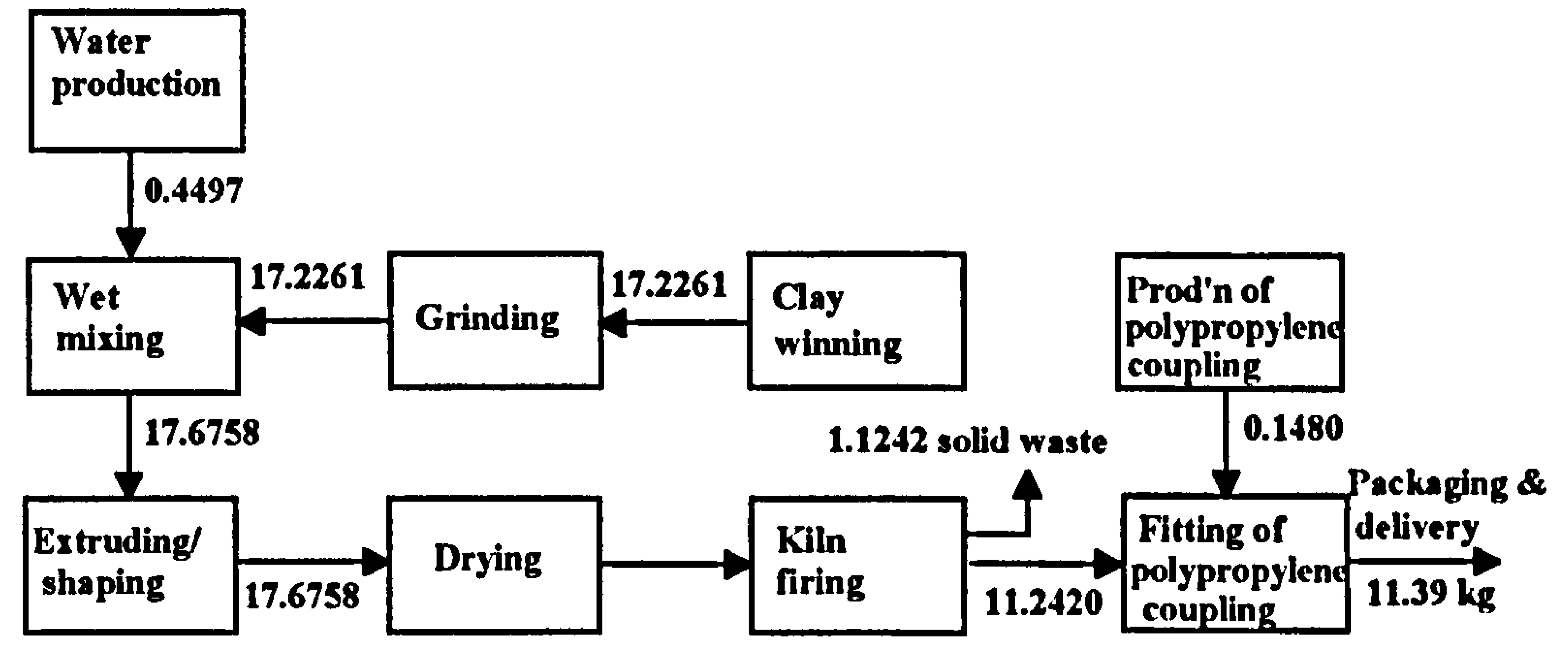
Water emissions	mg
COD	46
BOD	22
Salt	7
Acid	159
Metals	52
Cl^-	31
Suspended solids	24,646
HC	32
Phenol	20
Dissolved solids	18
Other organics	3

Solid waste	mg
Paper	1,000
Plastics	11,757
Metals	81,595
Organics	2
Other ref	511,541
Mineral waste	13,070,000
Slags/ash	129,342
Industrial waste	2,463
Fired clay	2,367,800
Unregulated chemicals	566

Packaging & delivery: Steel and polypropylene strapping - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, return distance 155 km

Appendix 24 Structural clay products

Production and road delivery of 100 mm vitrified clay pipes per metre length



Schematic flow diagram for the production of 100 mm vitrified clay pipes
All flows are in kg/m

Gross inputs and outputs associated with the production and road delivery of 100 mm vitrified clay pipes - kg /m

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	11.22
Electricity - delivered	4.75
Oil fuels - production & delivery	2.28
Oil fuels - delivered	9.45
Oil fuels - feedstock	6.48
Other fuels - production & delivery	4.71
Other fuels - delivered	40.34
Other fuels - feedstock	3.43
Total energy	82.64

Raw materials	mg
Barytes	2
Bauxite	234
Brine	36
Clay	17,226,100
Fe-Mn	99
Fluorspar	3
Iron ore	27,504
Lead	20
Limestone	8,291
Met coal	11,277
Sand	4
Water	2,521,600
Wood	107,640
Zinc	3
NaCl	740
Air	623
Sulphur	41

Air emissions	mg
Dust	8,163
CO	6,030
CO_2	4,261,700
SO_x	18,809
NO_x	43,601
HCl	445
F	1
HF	597
HC	23,516
Metals	2
CH_4	60,831

Primary fuels	MJ
Coal	10.13
Oil	12.45
Gas	46.02
Hydro	0.19
Nuclear	3.92
Total fuels	79.70
Primary feedstocks	**MJ**
Coal	0.35
Oil	6.39
Gas	1.45
Wood	1.62
Total feedstocks	9.82
Total fuels & feedstocks	82.53

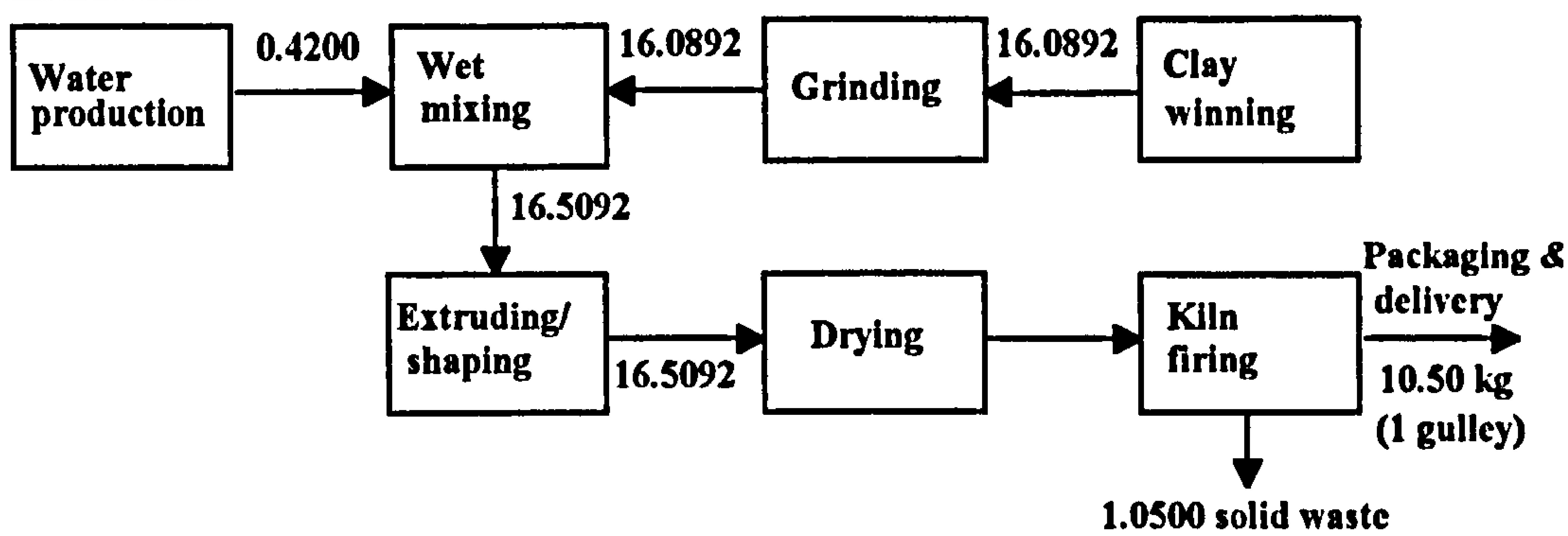
Water emissions	mg
COD	72
BOD	19
Acid	42
NO_3^-	3
Metals	53
NH_4^+	1
Cl^-	118
Dissolved organics	4
Suspended solids	3,614
Detergent/oil	6
HC	56
Phenol	10
Dissolved solids	30
Other N	1
Phosphate/P_2O_5	3
Other organics	37

Solid waste	mg
Paper	17
Plastics	221
Metals	13,870
Other ref	86,962
Mineral waste	5,026,500
Slags/ash	22,391
Industrial waste	1,834
Fired clay	1,124,200
Regulated chemicals	4
Unregulated chemicals	1,184

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: articulated vehicle, 24 tonne payload, returning empty, notional return distance 322 km

Appendix 25 Structural clay products

Production and road delivery of a vitrified clay gulley (width 195 mm, depth 335 mm)



Schematic flow diagram for the production of a vitrified clay gulley. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a vitrified clay gulley - per gulley

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	16.05
Electricity - delivered	6.79
Oil fuels - production & delivery	4.35
Oil fuels - delivered	30.10
Oil fuels - feedstock	0.06
Other fuels - production & delivery	7.96
Other fuels - delivered	70.73
Other fuels - feedstock	1.79
Total energy	137.83

Raw materials	mg
Barytes	2
Bauxite	155
Brine	35
Clay	16,089,200
Fe-Mn	88
Fluorspar	3
Iron ore	24,231
Lead	21
Limestone	7,247
Met coal	9,950
Sand	6
Water	3,272,200
Wood	99,230
Zinc	3
Air	512
Sulphur	34

Air emissions	mg
Dust	12,974
CO	3,118
CO_2	13,615,900
SO_x	61,135
NO_x	85,671
HCl	1,859
F	1
HF	26,264
HC	39,293
Metals	27
CH_4	109,433

Primary fuels	MJ
Coal	14.49
Oil	35.11
Gas	80.47
Hydro	0.27
Nuclear	5.63
Total fuels	135.98
Primary feedstocks	**MJ**
Coal	0.31
Oil	0.01
Wood	1.50
Total feedstocks	1.82
Total fuels & feedstocks	137.80

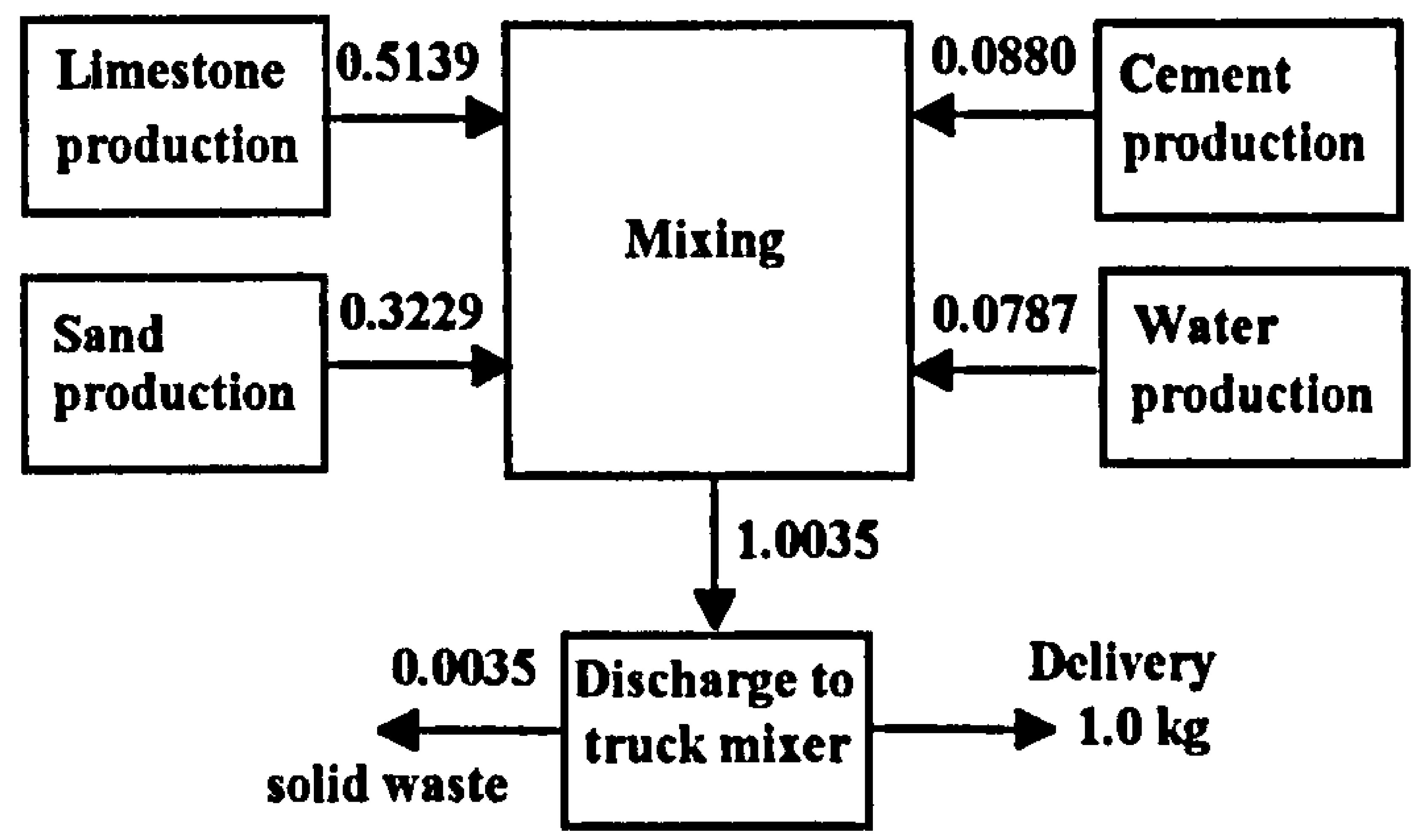
Water emissions	mg
COD	37
BOD	33
Acid	41
Metals	13
Suspended solids	3,280
HC	35
Phenol	33

Solid waste	mg
Paper	16
Plastics	204
Metals	12,820
Other ref	80,167
Mineral waste	4,729,900
Slags/ash	32,187
Industrial waste	3,844
Fired clay	1,050,000

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 12 tonne payload, returning empty, notional return distance 322 km

Appendix 26 Concrete and mortar products

Production and delivery of ready mixed concrete (20 MPa) - suitable for footings and foundations



Schematic flow diagram for the production of ready mixed concrete (20 MPa)
All flows are in kg

Gross inputs and outputs associated with the production & delivery of ready mixed concrete (20 MPa) /kg
Totals may not agree because of rounding errors

Energy	**MJ**
Electricity - production & delivery	0.18
Electricity - delivered	0.08
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.09
Other fuels - production & delivery	0.01
Other fuels - delivered	0.37
Total energy	0.75

Raw materials	**mg**
Bauxite	1
$CaSO_4$	4,398
Iron ore	206
Limestone	625,884
Met coal	85
Sand	335,354
Water	1,569,400
Shale	12,450
Air	13

Air emissions	**mg**
Dust	560
CO	87
CO_2	100,902
SO_x	620
H_2S	1
NO_x	244
HCl	11
HC	41
CH_4	143

Primary fuels	**MJ**
Coal	0.53
Oil	0.13
Gas	0.01
Nuclear	0.07
Total fuels	0.74
Primary feedstocks	**MJ**
Total feedstock	0.00
Total fuels & feedstock	0.75

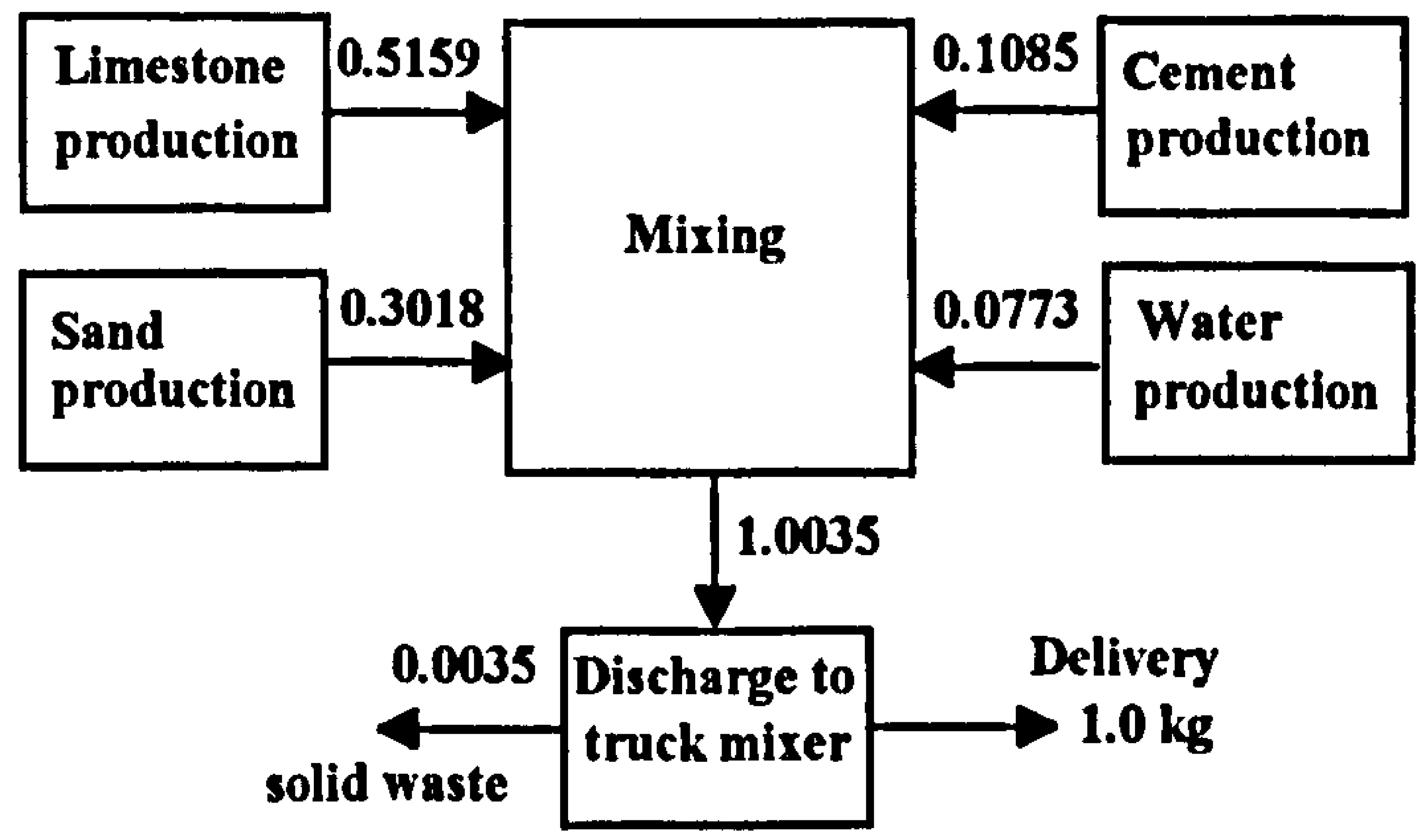
Water emissions	**mg**
Suspended solids	453

Solid waste	**mg**
Mineral waste	46,515
Slags/ash	367
Industrial waste	73,114

Packaging & delivery: Bulk delivery - no packaging
Road transport: rigid concrete mixer, 14.4 tonne payload, returning empty, return distance 13 km

Production and delivery of ready mixed concrete (30 MPa) - suitable for

- **floors - light foot and trolley traffic**
- **reinforced or pre-stressed concrete (mild exposure)**



Schematic flow diagram for the production of ready mixed concrete (30 MPa)
All flows are in kg

Gross inputs and outputs associated with the production & delivery of ready mixed concrete (30 MPa) /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.21
Electricity - delivered	0.09
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.10
Other fuels - production & delivery	0.02
Other fuels - delivered	0.45
Total energy	0.88

Raw materials	mg
Bauxite	1
$CaSO_4$	5,426
Iron ore	219
Limestone	654,124
Met coal	90
Sand	317,156
Water	1,527,400
Shale	15,363
Air	14

Air emissions	mg
Dust	684
CO	96
CO_2	122,162
SO_x	745
H_2S	2
NO_x	283
HCl	13
HF	1
HC	45
CH_4	173

Primary fuels	MJ
Coal	0.65
Oil	0.14
Gas	0.01
Nuclear	0.08
Total fuels	0.88
Primary feedstocks	**MJ**
Total feedstock	0.00
Total fuels & feedstock	0.88

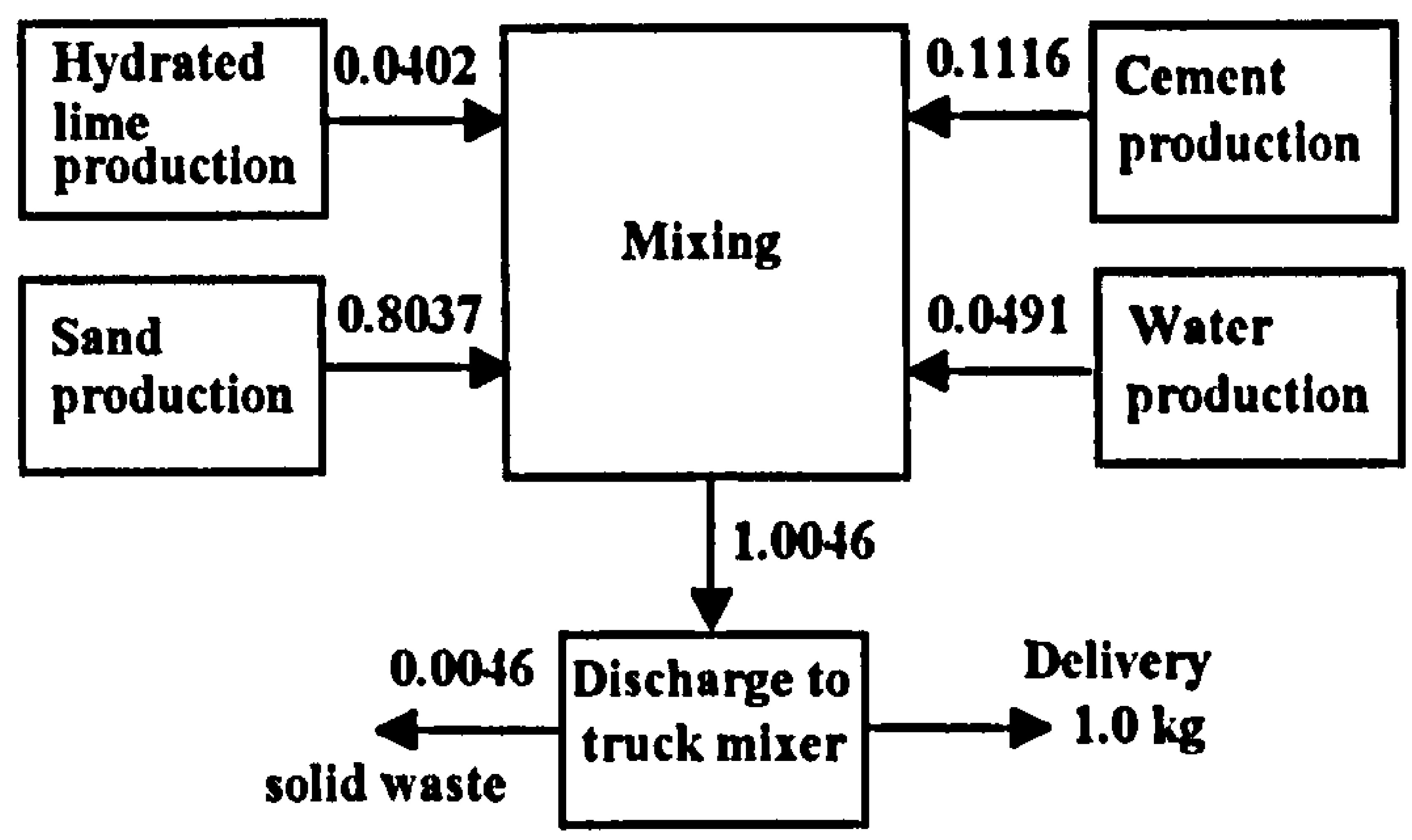
Water emissions	mg
Acid	1
Suspended solids	555

Solid waste	mg
Mineral waste	45,397
Slags/ash	428
Industrial waste	76,268

Packaging & delivery: Bulk delivery - no packaging
Road transport: rigid concrete mixer,14.4 tonne payload, returning empty, return distance 13 km

Appendix 28 Concrete and mortar products

Production and delivery of ready mixed 1 : 1 : 6 cement : lime : sand mortar (by volume)



Schematic flow diagram for the production of ready mixed cement : lime : sand mortar
All flows are in kg

Gross inputs and outputs associated with the production & delivery of ready mixed cement : lime : sand mortar /kg Totals may not agree because of rounding errors

Energy	**MJ**
Electricity - production & delivery	0.23
Electricity - delivered	0.10
Oil fuels - production & delivery	0.01
Oil fuels - delivered	0.10
Other fuels - production & delivery	0.04
Other fuels - delivered	0.64
Total energy	1.12

Primary fuels	**MJ**
Coal	0.68
Oil	0.14
Gas	0.21
Nuclear	0.08
Total fuels	1.11
Primary feedstocks	**MJ**
Total feedstock	0.00
Total fuels & feedstock	1.12

Raw materials	**mg**
Bauxite	1
$CaSO_4$	5,581
Iron ore	213
Limestone	196,419
Met coal	88
Sand	819,503
Water	3,524,400
Shale	15,799
Air	13

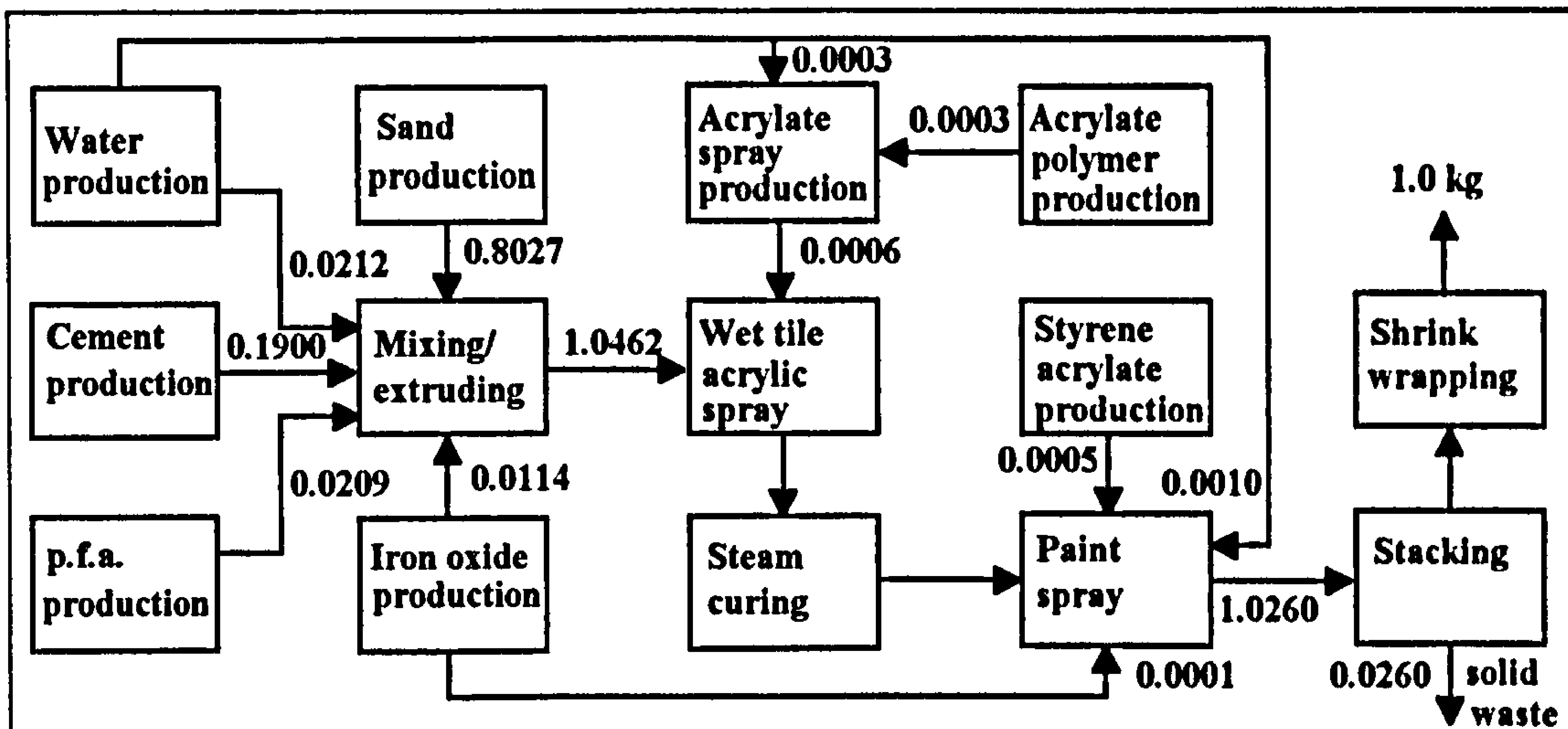
Water emissions	**mg**
Acid	1
Suspended solids	569

Solid waste	**mg**
Mineral waste	106,805
Slags/ash	464
Industrial waste	26,546

Air emissions	**mg**
Dust	753
CO	695
CO_2	159,597
SO_x	1,104
H_2S	2
NO_x	421
HCl	13
HC	129
CH_4	443

Packaging & delivery: Bulk delivery - no packaging
Road transport: rigid concrete mixer,14.4 tonne payload, returning empty, return distance 13 km

Production and road delivery of concrete roof tiles/kg



Schematic flow diagram for the production of concrete roof tiles
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of concrete roof tiles/kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.52
Electricity - delivered	0.22
Oil fuels - production & delivery	0.06
Oil fuels - delivered	0.37
Oil fuels - feedstock	0.05
Other fuels - production & delivery	0.04
Other fuels - delivered	0.96
Other fuels - feedstock	0.19
Total energy	2.42

Raw materials	mg
Bauxite	14
Brine	5
$CaSO_4$	9,502
Clay	7
Fe-Mn	8
Iron ore	13,550
Lead	1
Limestone	242,449
Met coal	842
Sand	829,582
Water	3,878,000
Wood	9,587
Shale	26,902
NaCl	4
Air	36
Sulphur	2

Air emissions	mg
Dust	1,384
CO	197
CO_2	255,889
SO_x	1,859
H_2S	3
NO_x	697
HCl	28
HF	1
HC	150
CH_4	416

Primary fuels	MJ
Coal	1.41
Oil	0.50
Gas	0.09
Hydro	0.01
Nuclear	0.19
Total fuels	2.20
Primary feedstocks	**MJ**
Coal	0.03
Oil	0.05
Gas	0.02
Wood	0.14
Total feedstocks	0.24
Total fuels & feedstocks	2.44

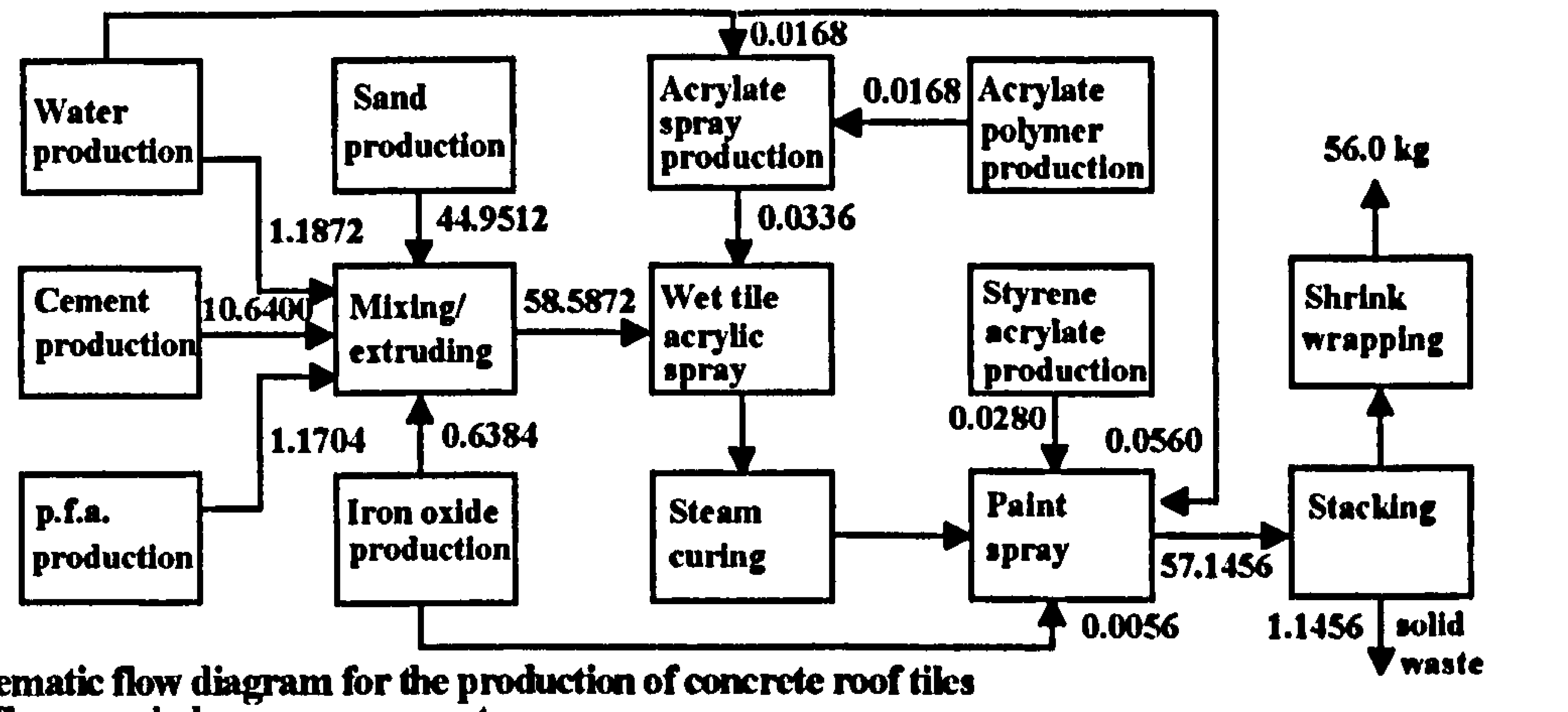
Water emissions	mg
COD	2
BOD	1
Acid	2
Metals	1
Suspended solids	2,267
HC	1

Solid waste	mg
Paper	50
Plastics	19
Metals	1,221
Other ref	7,635
Mineral waste	154,262
Slags/ash	1,429
Industrial waste	27,071
Unregulated chemicals	1

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, return distance 155 km

Appendix 30 Concrete and mortar products

Production and road delivery of concrete roof tiles/kg per sq.m



Schematic flow diagram for the production of concrete roof tiles
All flows are in kg per square metre

Gross inputs and outputs associated with the production and road delivery of concrete roof tiles - kg/sq. m

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	29.18
Electricity - delivered	12.35
Oil fuels - production & delivery	3.44
Oil fuels - delivered	20.95
Oil fuels - feedstock	2.99
Other fuels - production & delivery	2.17
Other fuels - delivered	53.84
Other fuels - feedstock	10.43
Total energy	135.34

Raw materials	mg
Barytes	4
Bauxite	779
Brine	286
$CaSO_4$	532,112
Clay	370
Fe-Mn	422
Fluorspar	14
Iron ore	758,832
Lead	59
Limestone	13,577,100
Met coal	47,141
Sand	46,456,600
Water	217,167,400
Wood	536,886
Zinc	16
Shale	1,506,500
NaCl	216
Air	2,006
Sulphur	132

Air emissions	mg
Dust	77,521
CO	11,041
CO_2	14,329,800
SO_x	104,088
H_2S	179
NO_x	39,063
NH_3	1
HCl	1,568
F	3
HF	65
HC	8,401
Metals	7
CH_4	23,298

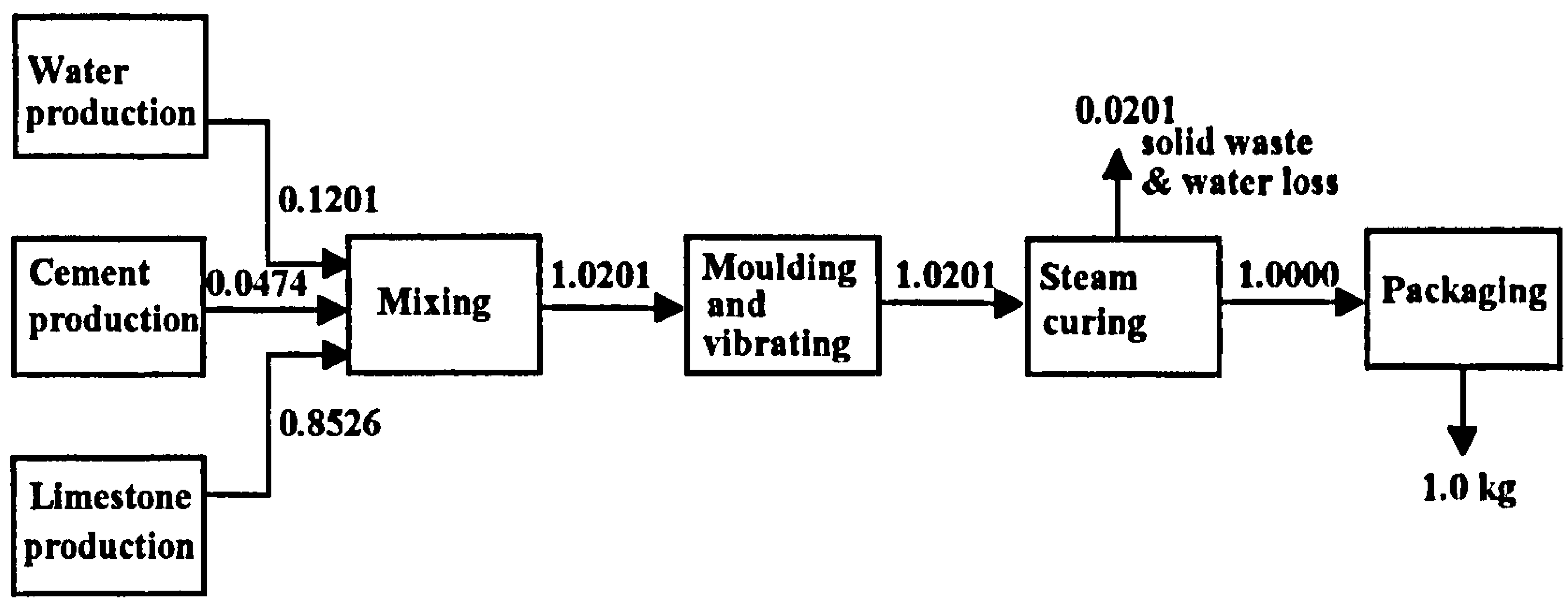
Primary fuels	MJ
Coal	79.13
Oil	28.36
Gas	4.83
Hydro	0.51
Nuclear	10.39
Total fuels	123.21
Primary feedstocks	**MJ**
Coal	1.48
Oil	2.75
Gas	0.98
Wood	8.05
Total feedstocks	13.26
Total fuels & feedstocks	136.47

Water emissions	mg
COD	102
BOD	36
Acid	89
Metals	36
Cl^-	4
Dissolved organics	1
Suspended solids	126,953
Detergent/oil	3
HC	35
Phenol	27
Dissolved solids	12
Other N	1

Solid waste	mg
Plastic containers	2
Paper	2,796
Plastics	1,089
Metals	68,374
Organics	2
Other ref	427,556
Mineral waste	8,638,700
Slags/ash	80,007
Industrial waste	1,516,000
Regulated chemicals	2
Unregulated chemicals	62

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 20 tonne payload, returning empty, return distance 155 km

Production and road delivery of dense concrete blocks/kg



Schematic flow diagram for the production of dense concrete blocks - 7 MPa
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of dense concrete blocks - 7 MPa/kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.19
Electricity - delivered	0.08
Oil fuels - production & delivery	0.03
Oil fuels - delivered	0.23
Oil fuels - feedstock	0.01
Other fuels - production & delivery	0.01
Other fuels - delivered	0.21
Other fuels - feedstock	0.17
Total energy	0.93

Primary fuels	MJ
Coal	0.38
Oil	0.28
Gas	0.03
Nuclear	0.07
Total fuels	0.75
Primary feedstocks	**MJ**
Coal	0.03
Wood	0.14
Total feedstocks	0.17
Total fuels & feedstocks	0.92

Raw materials	mg
Bauxite	13
Brine	2
$CaSO_4$	2,371
Fe-Mn	7
Iron ore	2,021
Lead	1
Limestone	913,533
Met coal	830
Sand	6,713
Water	268,944
Wood	9,450
Shale	6,713
Air	29
Sulphur	2

Water emissions	mg
Acid	1
Suspended solids	480

Solid waste	mg
Paper	1
Plastics	19
Metals	1,226
Other ref	7,635
Mineral waste	7,312
Slags/ash	499
Industrial waste	119,552

Air emissions	mg
Dust	382
CO	129
CO_2	76,715
SO_x	645
H_2S	1
NO_x	298
HCl	7
HC	77
CH_4	120

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 16 tonne payload, returning empty, return distance 129 km

Appendix 32 Concrete and mortar products

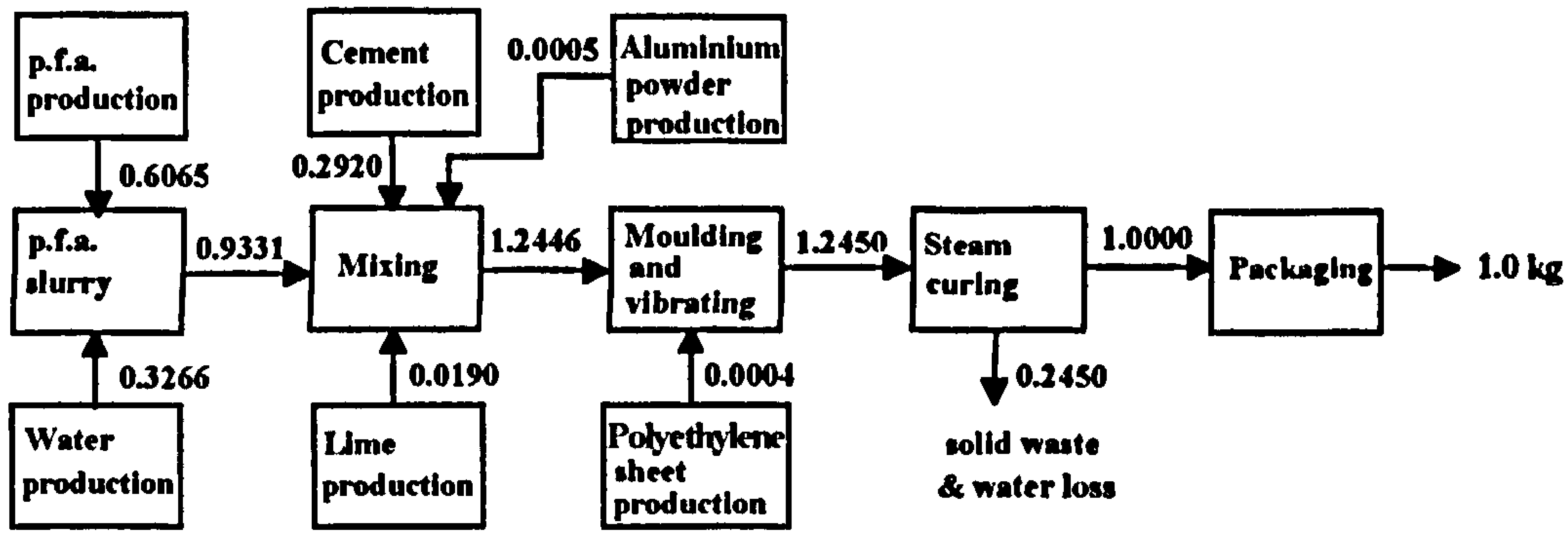
Production and road delivery of dense concrete blocks - per m^2

Gross inputs and outputs associated with the production and road delivery of dense concrete blocks - per m^2 (derived from figures shown in Appendix 31 Totals may not agree because of rounding errors			
Input/output	**Units**	**(440x215x100) mm 194 kg/sq.m**	**(440x215x140) mm 271.5 kg/sq.m**
Energy			
Electricity - production & delivery	MJ	37.45	52.41
Electricity - delivered	MJ	15.88	22.22
Oil fuels - production & delivery	MJ	6.52	9.12
Oil fuels - delivered	MJ	44.17	61.82
Oil fuels - feedstock	MJ	1.09	1.52
Other fuels - production & delivery	MJ	1.72	2.41
Other fuels - delivered	MJ	40.21	56.28
Other fuels - feedstock	MJ	32.66	45.71
Total energy	MJ	179.7	251.49
Fuels			
Coal	MJ	72.8	101.88
Oil	MJ	53.6	75.01
Gas	MJ	5.38	7.53
Hydro	MJ	0.67	0.93
Nuclear	MJ	13.1	18.34
Total fuels	MJ	145.55	203.69
Feedstock			
Coal	MJ	5.04	7.05
Oil	MJ	0.22	0.30
Wood	MJ	27.64	38.69
Total feedstock	MJ	32.9	46.04
Total fuels & feedstock	MJ	178.45	249.73
Raw materials			
Barytes	mg	15	21
Bauxite	mg	2,546	3,563
Brine	mg	467	654
$CaSO_4$	mg	459,974	643,727
Clay	mg	38	53
Fe-Mn	mg	1,444	2,020
Fluorspar	mg	46	65
Iron ore	mg	392,061	548,683
Lead	mg	217	303
Limestone	mg	177,225,400	248,024,200
Met coal	mg	160,952	225,250
Sand	mg	1,302,300	1,822,500
Tin		1	2
Water	mg	52,175,100	73,018,200
Wood	mg	1,833,400	2,565,800
Zinc	mg	57	80
Shale	mg	1,302,300	1,822,500
Air	mg	5,708	7,988
Sulphur	mg	376	526
Air emissions			
Dust	mg	74,046	103,626
CO	mg	25,077	35,095
CO2	mg	14,883,200	20,828,800
SOx	mg	125,042	174,995
H_2S	mg	154	216
NOx	mg	57,762	80,837
HCl	mg	1,424	1,993
F	mg	9	12
HF	mg	62	86
HC	mg	14,987	20,976
Metals	mg	7	10
CH4	mg	23,217	32,491
Water emissions			
COD	mg	62	86
BOD	mg	50	70
Acid	mg	154	215
Metal ions	mg	44	62
F	mg	1	2
Suspended solids	mg	93,074	130,255
Hydrocarbons	mg	56	79
Phenol	mg	50	69
Solid waste			
Paper	mg	288	403
Plastics	mg	3,756	5,256
Metals	mg	237,830	333,840
Organics	mg	9	12
Other refuse	mg	1,481,200	2,072,900
Mineral waste	mg	1,418,600	1,985,300
Slags\ash	mg	96,725	135,365
Industrial waste	mg	23,193,200	32,458,500

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 16 tonne payload, returning empty, return distance 129 km

Appendix 33 Concrete and mortar products

Production and road delivery of aerated concrete block /kg



Schematic flow diagram for the production of aerated concrete blocks, 4.0 MPa. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of aerated concrete blocks (4.0 MPa) /kg
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.78
Electricity - delivered	0.35
Oil fuels - production & delivery	0.24
Oil fuels - delivered	1.63
Oil fuels - feedstock	0.03
Other fuels - production & delivery	0.06
Other fuels - delivered	1.32
Other fuels - feedstock	0.18
Total energy	4.59

Primary fuels	MJ
Coal	1.93
Oil	1.90
Gas	0.23
Hydro	0.05
Nuclear	0.27
Total fuels	4.37
Primary feedstocks	**MJ**
Coal	0.03
Oil	0.02
Gas	0.01
Wood	0.14
Total feedstocks	0.21
Total fuels & feedstocks	4.58

Raw materials	mg
Bauxite	2,009
Brine	254
$CaSO_4$	14,602
Fe-Mn	9
Fluorspar	36
Iron ore	2,444
Lead	2
Limestone	398,043
Met coal	1,004
Sand	41,340
Water	1,098,500
Wood	9,450
Shale	41,340
Sodium chloride	3
Air	287
Sulphur	19

Water emissions	mg
COD	2
BOD	2
Acid	2
Metals	1
F	1
Suspended solids	1,915
HC	2
Phenol	2

Air emissions	mg
Dust	2,006
CO	858
CO_2	473,948
SO_x	4,415
H_2S	5
NO_x	1,448
HCl	38
F	3
HF	2
HC	400
Metals	1
CH_4	669
Hydrogen	56

Solid waste	mg
Paper	1
Plastics	19
Metals	1,226
Other ref	7,635
Mineral waste	29,061
Slags/ash	1,692
Industrial waste	64,921

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 16 tonne payload, returning empty, return distance 129 km

Appendix 34 Concrete and mortar products

Production and road delivery of aerated concrete blocks - per m^2

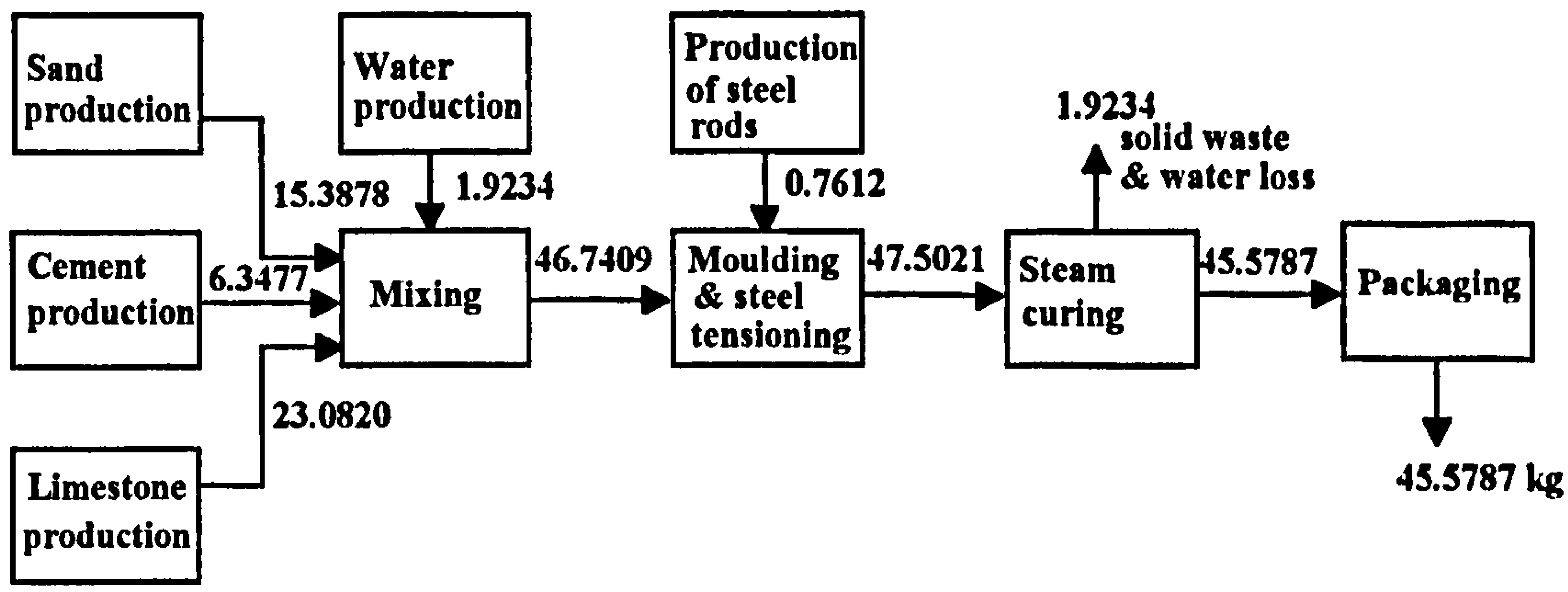
Gross inputs and outputs associated with the production and road delivery of aerated concrete blocks - per m^2
(derived from figures shown in Appendix 33. Totals may not agree because of rounding errors

Input/output	Units	(440x215x100) mm 75 kg/sq.m	(440x215x140) mm 105 kg/sq.m
Energy			
Electricity - production & delivery	MJ	58.47	81.86
Electricity - delivered	MJ	26.50	37.10
Oil fuels - production & delivery	MJ	17.97	25.16
Oil fuels - delivered	MJ	122.34	171.27
Oil fuels - feedstock	MJ	2.38	3.33
Other fuels - production & delivery	MJ	4.23	5.92
Other fuels - delivered	MJ	98.94	138.51
Other fuels - feedstock	MJ	13.56	18.98
Total energy	MJ	344.38	482.13
Fuels			
Coal	MJ	144.41	202.18
Oil	MJ	142.20	199.08
Gas	MJ	17.06	23.88
Hydro	MJ	3.69	5.17
Nuclear	MJ	20.61	28.86
Total fuels	MJ	327.98	459.18
Feedstock			
Coal	MJ	2.36	3.30
Oil	MJ	1.81	2.53
Gas	MJ	0.65	0.91
Wood	MJ	10.69	14.96
Total feedstock	MJ	15.50	21.70
Total fuels & feedstock	MJ	343.48	480.87
Raw materials			
Barytes	mg	10	14
Bauxite	mg	150,707	210,990
Brine	mg	19,042	26,660
$CaSO_4$	mg	1,095,100	1,533,200
Clay	mg	15	21
Fe-Mn	mg	662	927
Fluorspar	mg	2,736	3,830
Iron ore	mg	183,293	256,610
Lead	mg	129	180
Limestone	mg	29,853,200	41,794,500
Met coal	mg	75,271	105,379
Sand	mg	3,100,500	4,340,700
Water	mg	82,388,500	115,343,900
Wood	mg	708,782	992,295
Zinc	mg	22	31
Shale	mg	3,100,500	4,340,700
Sodium chloride	mg	189	264
Nitrogen	mg	22	31
Air	mg	21,503	30,104
Sulphur	mg	1,416	1,982
Air emissions			
Dust	mg	150,438	210,613
CO	mg	64,351	90,092
CO2	mg	35,546,100	49,764,600
SOx	mg	331,128	463,579
H_2S	mg	367	514
NOx	mg	108,599	152,038
HCl	mg	2,855	3,997
F	mg	220	307
HF	mg	120	168
HC	mg	29,966	41,952
Metals	mg	108	152
CH4	mg	50,136	70,190
Hydrogen	mg	4,208	5,892
Water emissions			
COD	mg	179	251
BOD	mg	137	191
Acid	mg	169	237
Metal ions	mg	60	83
Cl^-	mg	23	32
F^-	mg	77	108
Dissolved organics	mg	1	1
Suspended solids	mg	143,598	201,037
Detergent/oil	mg	3	4
Hydrocarbons	mg	144	202
Phenol	mg	132	185
Dissolved solids	mg	11	15
Solid waste			
Paper	mg	111	156
Plastics	mg	1,456	2,039
Metals	mg	91,945	128,723
Organics	mg	6	8
Other refuse	mg	572,620	801,668
Mineral waste	mg	2,179,600	3,051,400
Slags\ash	mg	126,898	177,657
Industrial waste	mg	4,869,100	6,816,700
Regulated chemicals	mg	2	3
Unregulated chemicals	mg	54	75

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport: rigid vehicle, 16 tonne payload, returning empty, return distance 129 km

Appendix 35 Concrete and mortar products

Production and road delivery of pre-stressed concrete lintels (255 x 75) mm - per metre length



Schematic flow diagram for the production of pre-stressed concrete lintels (255x75)mm
All flows are in kg per metre length

Gross inputs and outputs associated with the production and road delivery of pre-stressed concrete lintels (255x75) mm - per metre length Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	21.39
Electricity - delivered	9.12
Oil fuels - production & delivery	2.40
Oil fuels - delivered	16.29
Oil fuels - feedstock	0.32
Other fuels - production & delivery	1.52
Other fuels - delivered	27.65
Other fuels - feedstock	16.02
Total energy	94.72

Raw materials	mg
Barytes	4
Bauxite	5,948
Brine	788
$CaSO_4$	317,376
Clay	3
Fe-Mn	3,370
Fluorspar	108
Iron ore	1,031,800
Lead	42
Limestone	31,423,200
Met coal	424,436
Sand	16,286,400
Water	91,978,200
Wood	183,422
Zinc	47
Shale	898,536
Sodium chloride	10
Air	2,293
Sulphur	151

Air emissions	mg
Dust	51,338
CO	10,513
CO_2	9,048,600
SO_x	138,974
H_2S	106
NO_x	31,292
HCl	910
F	19
HF	39
HC	7,013
Metals	7
CH_4	17,509

Primary fuels	MJ
Coal	46.11
Oil	21.15
Gas	3.00
Hydro	0.47
Nuclear	7.60
Total fuels	78.34
Primary feedstocks	**MJ**
Coal	13.29
Oil	0.13
Gas	0.02
Wood	2.77
Total feedstocks	16.21
Total fuels & feedstocks	94.55

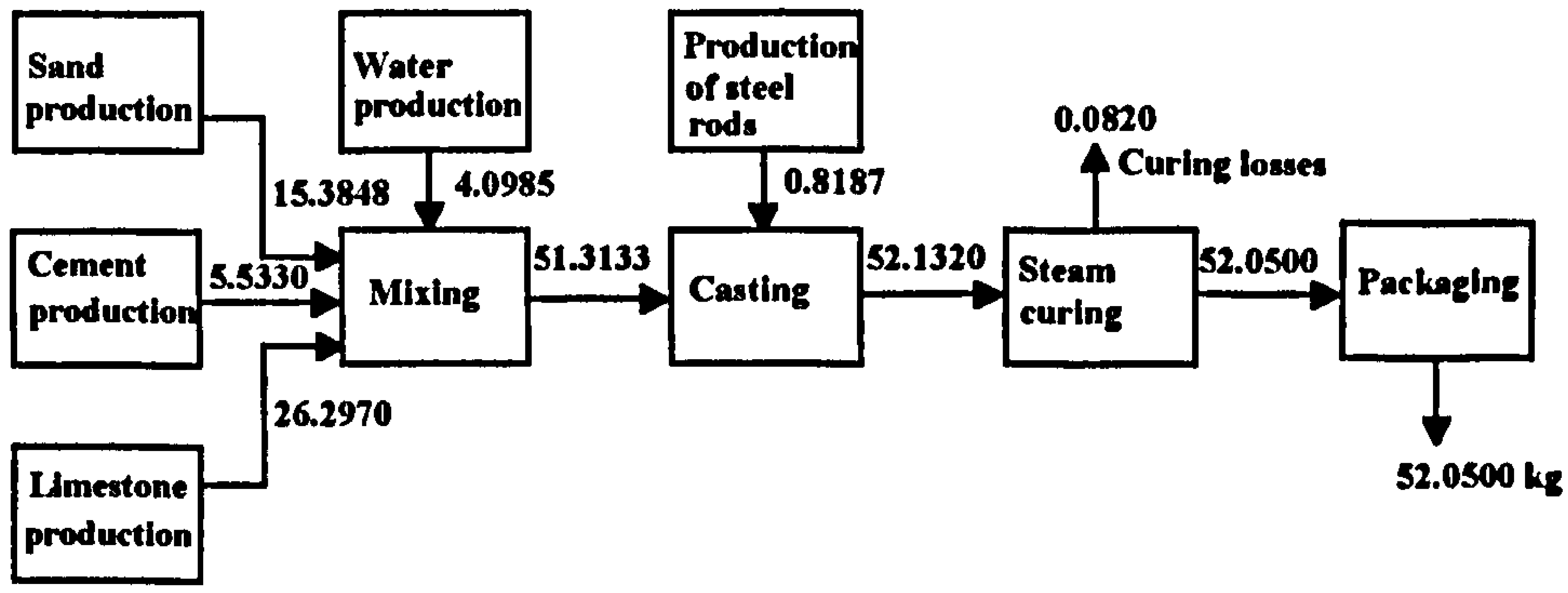
Water emissions	mg
COD	24
BOD	20
Acid	230
Metals	60
Cl^-	2
F^-	3
Suspended solids	154,159
HC	23
Phenol	19

Solid waste	mg
Paper	23
Plastics	2,248
Metals	6,256
Organics	2
Other ref	128,930
Mineral waste	3,808,700
Slags/ash	108,469
Industrial waste	3,470,500
Unregulated chemicals	16

Packaging & delivery: Polypropylene strapping using galvanised steel clips - delivered on wooden pallets
Road transport: articulated vehicle, 25 tonne payload, returning empty, average return distance 200 km

Appendix 36 Concrete and mortar products

Production and road delivery of reinforced concrete lintels (100 x 143) mm - per 1500 mm length



Schematic flow diagram for the production of reinforced concrete lintels (100x143)mm
All flows are in kg per 1500 mm length

Gross inputs and outputs associated with the production and road delivery of reinforced concrete lintels (100x143) mm - per 1500 mm length Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	21.64
Electricity - delivered	9.23
Oil fuels - production & delivery	3.41
Oil fuels - delivered	23.13
Oil fuels - feedstock	0.50
Other fuels - production & delivery	1.47
Other fuels - delivered	24.54
Other fuels - feedstock	17.63
Total energy	101.54

Primary fuels	MJ
Coal	43.07
Oil	28.55
Gas	3.57
Hydro	0.48
Nuclear	7.65
Total fuels	83.32
Primary feedstocks	**MJ**
Coal	14.49
Oil	0.15
Gas	0.02
Wood	3.16
Total feedstocks	17.82
Total fuels & feedstocks	101.14

Raw materials	mg
Barytes	6
Bauxite	6,486
Brine	882
$CaSO_4$	276,649
Clay	4
Fe-Mn	3,674
Fluorspar	118
Iron ore	1,124,900
Lead	73
Limestone	33,626,800
Met coal	462,739
Sand	16,168,000
Water	94,007,900
Wood	209,464
Zinc	53
Shale	783,233
Sodium chloride	11
Nitrogen	1
Air	3,385
Sulphur	223

Water emissions	mg
COD	32
BOD	27
Acid	247
Metals	64
Cl^-	3
F	4
Suspended solids	161,495
HC	31
Phenol	26
Other organics	1

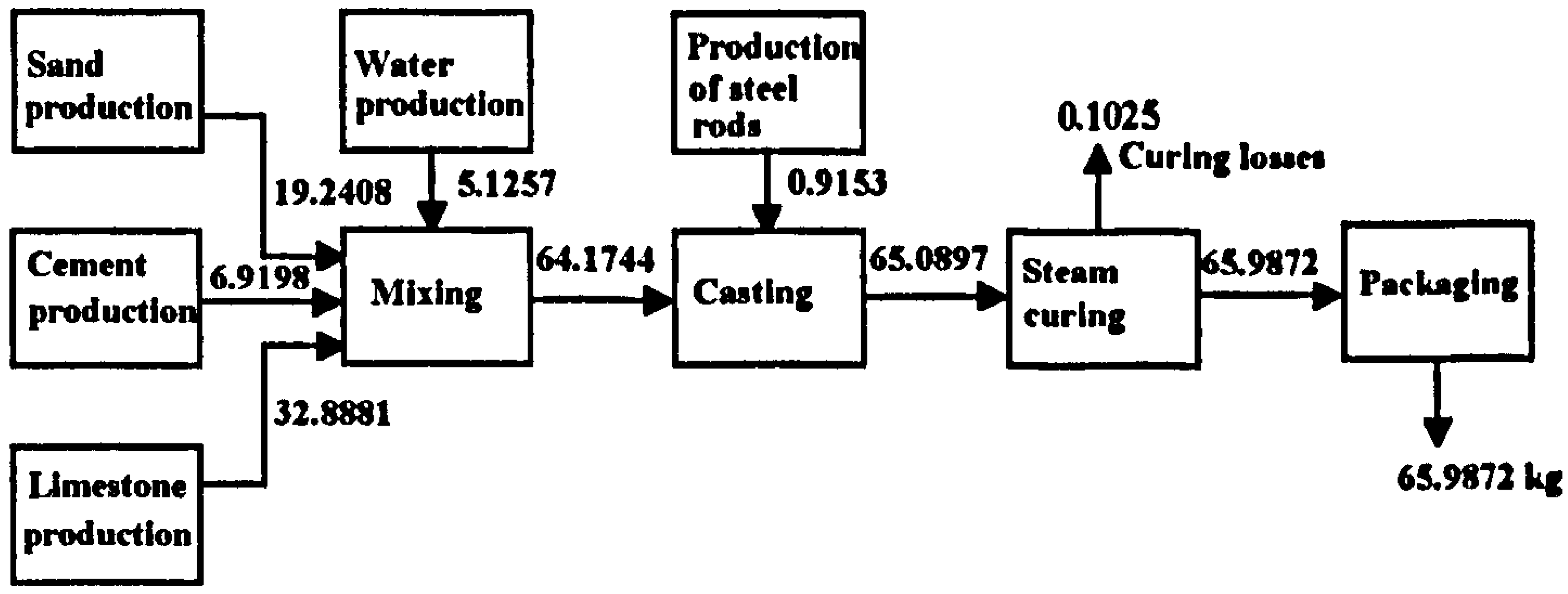
Solid waste	mg
Paper	26
Plastics	2,567
Metals	7,144
Organics	4
Other ref	147,235
Mineral waste	3,888,900
Slags/ash	114,787
Industrial waste	3,713,000
Unregulated chemicals	18

Air emissions	mg
Dust	48,272
CO	14,687
CO_2	8,895,100
SO_x	144,790
H_2S	93
NO_x	36,555
HCl	845
F	21
HF	36
HC	8,969
Metals	7
CH_4	17,297

Packaging & delivery: Polypropylene strapping using galvanised steel clips - delivered on wooden pallets
Road transport: articulated vehicle, 25 tonne payload, returning empty, average return distance 200 km

Appendix 37 Concrete and mortar products

Production and road delivery of reinforced concrete lintels (125 x 143) mm - per 1500 mm length



Schematic flow diagram for the production of reinforced concrete lintels (125x143)mm
All flows are in kg per 1500 mm length

Gross inputs and outputs associated with the production and road delivery of reinforced concrete lintels (125x143) mm - per 1500 mm length Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	26.42
Electricity - delivered	11.26
Oil fuels - production & delivery	4.22
Oil fuels - delivered	28.66
Oil fuels - feedstock	0.62
Other fuels - production & delivery	1.76
Other fuels - delivered	30.54
Other fuels - feedstock	20.21
Total energy	123.68

Primary fuels	MJ
Coal	53.27
Oil	35.31
Gas	4.25
Hydro	0.57
Nuclear	9.34
Total fuels	103.39
Primary feedstocks	**MJ**
Coal	16.28
Oil	0.18
Gas	0.03
Wood	3.94
Total feedstocks	20.44
Total fuels & feedstocks	123.18

Raw materials	mg
Barytes	8
Bauxite	7,289
Brine	999
$CaSO_4$	345,987
Clay	4
Fe-Mn	4,130
Fluorspar	132
Iron ore	1,264,100
Lead	91
Limestone	42,019,000
Met coal	520,008
Sand	20,220,300
Water	115,662,500
Wood	261,522
Zinc	67
Shale	979,542
Sodium chloride	14
Nitrogen	1
Air	4,120
Sulphur	271

Water emissions	mg
COD	39
BOD	33
Acid	283
Metals	74
Cl^-	3
F^-	4
Suspended solids	184,952
HC	38
Phenol	33
Dissolved solids	1
Other organics	1

Air emissions	mg
Dust	59,556
CO	18,130
CO_2	11,002,200
SO_x	168,923
H_2S	116
NO_x	44,618
HCl	1,045
F	24
HF	45
HC	10,913
Metals	8
CH_4	20,769

Solid waste	mg
Paper	33
Plastics	3,208
Metals	8,920
Organics	5
Other ref	183,831
Mineral waste	4,666,700
Slags/ash	133,028
Industrial waste	4,643,500
Unregulated chemicals	22

Packaging & delivery: Polypropylene strapping using galvanised steel clips - delivered on wooden pallets
Road transport: articulated vehicle, 25 tonne payload, returning empty, average return distance 200 km

Appendix 38 Concrete and mortar products

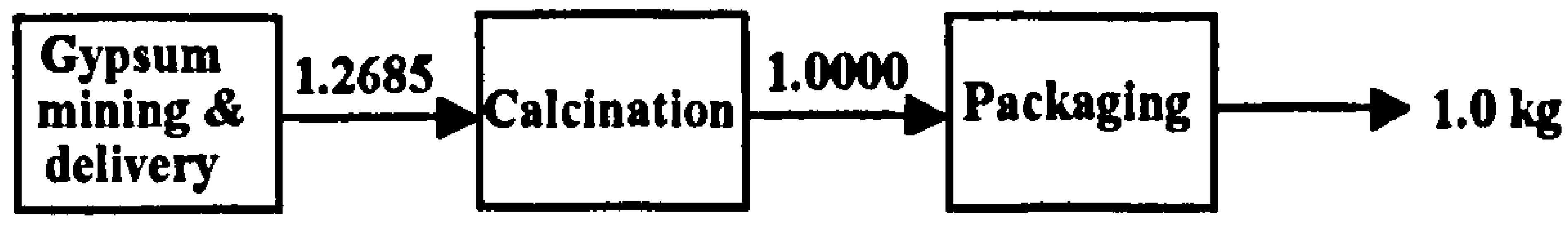
Production and road delivery of dual lintel systems - per 1500 mm

Gross inputs and outputs associated with the production and road delivery of dual lintel systems - per 1500 mm
Outer leaf: reinforced concrete (100 x 143) mm. Inner leaf as specified below (125 x 143) mm.
(derived from figures shown in Appendices 36, 37, 45, 53) Totals may not agree because of rounding errors

Input/output	Units	Inner leaf		
		Reinforced concrete	Timber	Rolled steel joist
Energy				
Electricity - production & delivery	MJ	48.05	30.77	241.47
Electricity - delivered	MJ	20.49	13.10	105.03
Oil fuels - production & delivery	MJ	7.63	8.44	14.75
Oil fuels - delivered	MJ	51.78	57.94	99.87
Oil fuels - feedstock	MJ	1.12	0.60	2.50
Other fuels - production & delivery	MJ	3.22	1.48	26.65
Other fuels - delivered	MJ	55.08	24.65	88.57
Other fuels - feedstock	MJ	37.84	248.40	548.88
Total energy	MJ	225.23	385.38	1,127.72
Fuels				
Coal	MJ	96.34	51.40	246.08
Oil	MJ	63.86	67.68	148.31
Gas	MJ	7.82	5.66	867,738.00
Hydro	MJ	1.06	0.63	8.52
Nuclear	MJ	17.00	10.86	86.40
Lignite	MJ	0.00	0	0.02
Sulphur	MJ	0.00	0	1.46
Recovered	MJ	-0.01	0	-1.62
Total fuels	MJ	186.07	136.23	575.94
Feedstock				
Coal	MJ	30.78	14.64	546.52
Oil	MJ	0.33	0.15	1.90
Gas	MJ	0.05	0.02	0.03
Wood	MJ	7.1	233.79	3.16
Total feedstock	MJ	38.26	248.60	551.61
Total fuels & feedstock	MJ	224.33	384.83	1,127.55
Raw materials				
Barytes	mg	14	8	12
Bauxite	mg	13,775	6,552	245,022
Brine	mg	1,881	906	30,930
$CaSO_4$	mg	622,638	276,649	276,652
Clay	mg	8	3	3
Fe-Mn	mg	7,804	3,712	138,830
Fluorspar	mg	250	119	4,448
Iron ore	mg	2,389,000	1,136,400	42,425,400
Lead	mg	163	92	135
Limestone	mg	75,645,900	33,630,900	48,233,500
Met coal	mg	982,747	467,464	17,451,500
Sand	mg	36,388,300	16,168,000	16,168,100
Water	mg	209,670,400	96,265,700	668,774,100
Wood	mg	470,986	15,503,000	209,464
Zinc	mg	120	53	53
Shale	mg	1,762,800	783,233	783,241
NaCl	mg	25	11	15
Nitrogen	mg	2	1	130
Air	mg	7,505	4,100	2,398,700
Sulphur	mg	494	270	157,924
Air emissions				
Dust	mg	107,828	54,371	304,863
CO	mg	32,817	38,971	85,618
CO2	mg	19,897,300	12,350,100	49,971,000
SOx	mg	313,713	163,432	3,705,300
H_2S	mg	209	93	93
NOx	mg	81,173	70,043	380,732
HCl	mg	1,890	1,006	4,825
F	mg	45	21	1,159
HF	mg	82	45	235
HC	mg	19,881	19,090	108,057
Lead	mg	0	2	0
Metals	mg	15	8	101
CH4	mg	38,066	19,835	305,223
Water emissions				
COD	mg	71	73	170
BOD	mg	59	63	139
Salt	mg	0	0	1
Acid	mg	530	270	8,005
Metal ions	mg	139	72	1,982
Cl^-	mg	6	3	35
F	mg	7	3	126
Suspended solids	mg	346,447	163,138	5,482,300
Hydrocarbons	mg	69	68	175
Phenol	mg	59	63	139
Dissolved solids	mg	1	0	2
Na^+	mg	0	0	1
Other organics	mg	1	1	1
Solid waste				
Paper	mg	59	26	26
Plastics	mg	5,776	2,569	2,574
Metals	mg	16,064	7,144	7,144
Organics	mg	8	5	7
Other refuse	mg	331,067	147,235	147,235
Mineral waste	mg	8,555,700	3,962,100	65,254,300
Slags\ash	mg	247,815	132,935	3,227,800
Industrial waste	mg	8,356,500	3,717,200	3,726,300
Unregulated chemicals	mg	40	18	18

Appendix 39 Gypsum plaster products

Production and road delivery of bagged finishing plaster /kg



Schematic flow diagram for the production of bagged finishing plaster
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of bagged finishing plaster /kg

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.65
Electricity - delivered	0.28
Oil fuels - production & delivery	0.09
Oil fuels - delivered	0.59
Oil fuels - feedstock	0.02
Other fuels - production & delivery	0.09
Other fuels - delivered	0.75
Other fuels - feedstock	0.28
Total energy	2.74

Raw materials	mg
Bauxite	13
Brine	236
$CaSO_4$	1,268,500
Clay	557
Fe-Mn	7
Iron ore	2,139
Lead	4
Limestone	752
Met coal	879
Water	464,772
Wood	21,348
Air	488
Sulphur	32

Air emissions	mg
Dust	385
CO	416
CO_2	137,610
SO_x	1,076
NO_x	1,269
HCl	11
HF	1
HC	548
CH_4	1,276

Primary fuels	MJ
Coal	0.59
Oil	0.73
Gas	0.87
Hydro	0.01
Nuclear	0.23
Total fuels	2.43
Primary feedstocks	**MJ**
Coal	0.03
Wood	0.25
Total feedstocks	0.28
Total fuels & feedstocks	2.71

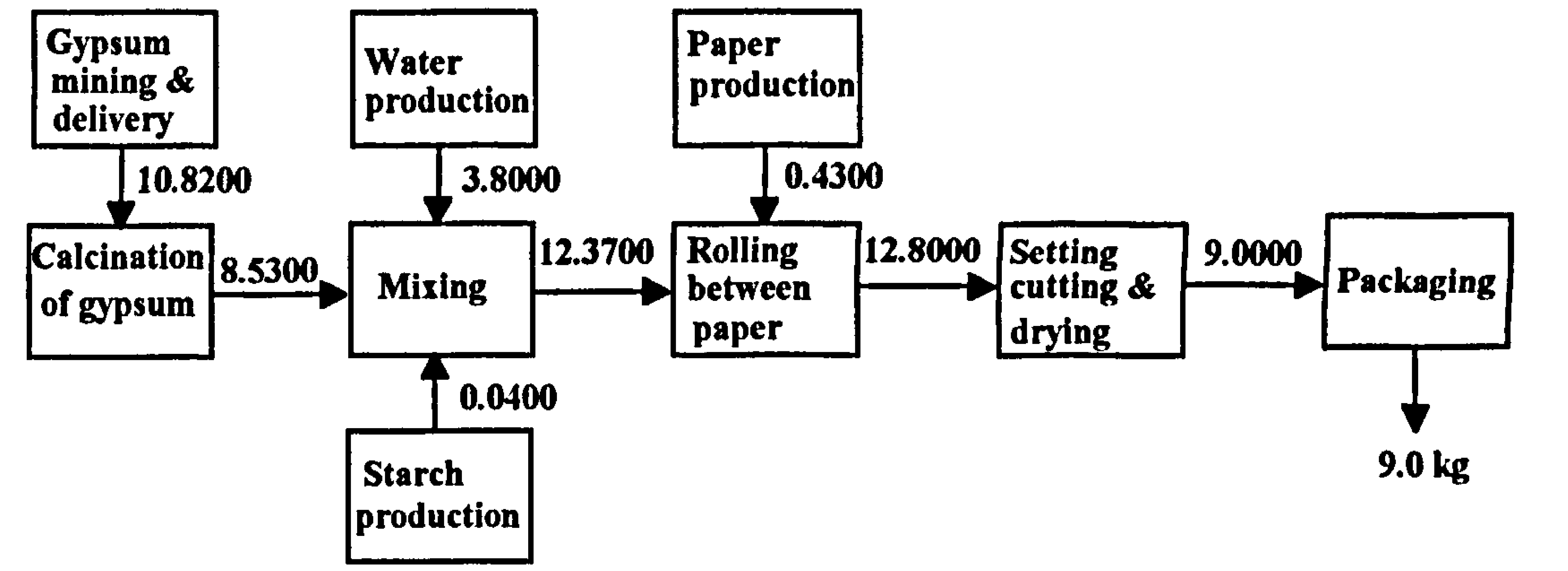
Water emissions	mg
COD	60
BOD	6
Acid	2
Metals	1
Suspended solids	120,220
HC	1
Phenol	1

Solid waste	mg
Plastic containers	3
Paper	4,214
Plastics	27
Metals	373
Other ref	7,635
Mineral waste	7,505
Slags/ash	1,358
Industrial waste	80

Packaging & delivery: Packed in paper sacks - delivered on wooden pallets
Road transport (notional): rigid vehicle, 20 tonne payload, returning empty, average return distance 300 km

Appendix 40 Gypsum plaster products

Production and road delivery of 12.5 mm plasterboard - per square metre



Schematic flow diagram for the production of 12.5 mm plasterboard
All flows are in kg per square metre

Gross inputs and outputs associated with the production and road delivery of 12.5 mm plasterboard - per sq.metre
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	9.97
Electricity - delivered	4.30
Oil fuels - production & delivery	0.98
Oil fuels - delivered	6.55
Oil fuels - feedstock	0.21
Other fuels - production & delivery	2.14
Other fuels - delivered	18.96
Other fuels - feedstock	11.93
Total energy	55.04

Primary fuels	MJ
Coal	8.90
Oil	8.55
Gas	21.56
Hydro	0.25
Nuclear	3.60
Total fuels	42.85
Primary feedstocks	**MJ**
Coal	0.22
Oil	0.05
Gas	0.03
Wood	10.88
Total feedstocks	11.98
Total fuels & feedstocks	54.84

Raw materials	mg
Barytes	3
Bauxite	100
Brine	26,862
$CaSO_4$	10,819,900
Clay	56,854
Fe-Mn	57
Fluorspar	2
Iron ore	16,924
Lead	42
Limestone	11,401
Met coal	6,959
Sand	1,897
Water	43,302,900
Wood	1,224,100
Zinc	15
Phosphate	4,732
Nitrogen	2
Air	55,161
Sulphur	2,971

Water emissions	mg
COD	6,102
BOD	705
Salt	1
Acid	28
NO_3^-	54
Metals	43
Cl^-	27
Sulphur	4
Dissolved organics	2
Suspended solids	1,032,800
HC	14
Phenol	7
Dissolved solids	165
Phosphorus	10
Other N	89

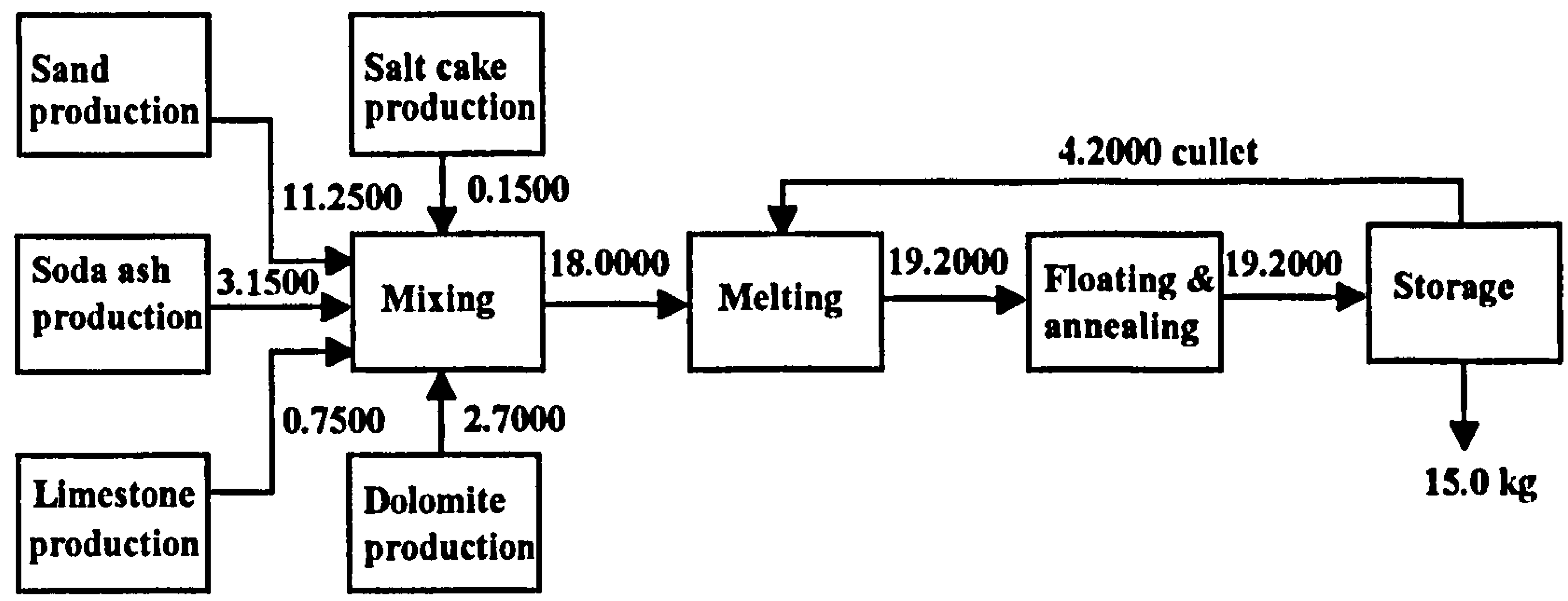
Air emissions	mg
Dust	7,080
CO	4,382
CO_2	2,308,900
SO_x	17,815
H_2S	31
Mercaptan	9
NO_x	22,468
HCl	182
F	1
HF	9
HC	11,162
Metals	3
CH_4	30,631

Solid waste	mg
Plastic containers	283
Paper	430,074
Plastics	959
Metals	1,497
Organics	2
Other ref	7,649
Mineral waste	140,262
Slags/ash	20,043
Industrial waste	940

Packaging & delivery: Steel strapping - delivered on wooden pallets
Road transport(notional): rigid vehicle, 20 tonne payload, returning empty, average return distance 300 km

Appendix 41 Glass products

Production and road delivery of 6 mm flat glass - per square metre



Schematic flow diagram for the production of 6 mm flat glass
All flows are in kg per square metre

Gross inputs and outputs associated with the production and road delivery of 6 mm flat glass - per square metre

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	18.91
Electricity - delivered	8.00
Oil fuels - production & delivery	13.24
Oil fuels - delivered	91.64
Oil fuels - feedstock	0.22
Other fuels - production & delivery	8.40
Other fuels - delivered	78.99
Other fuels - feedstock	0.27
Total energy	219.69

Primary fuels	MJ
Coal	17.37
Oil	102.41
Gas	87.92
Hydro	0.32
Nuclear	6.69
Other	4.35
Sulphur	0.35
Recovered	-0.38
Total fuels	219.02
Primary feedstocks	**MJ**
Coal	0.29
Total feedstocks	0.29
Total fuels & feedstocks	219.31

Raw materials	mg
Barytes	4
Bauxite	129
Brine	5,009,100
Fe-Mn	73
Fluorspar	2
Iron ore	22,382
Lead	41
Limestone	4,065,500
Met coal	9,200
Sand	11,250,000
Water	73,518,200
Sodium chloride	3
Dolomite	2,700,000
Nitrogen	23
Air	568,707
Sulphur	37,442

Water emissions	mg
COD	106
BOD	95
Salt	1,481
Acid	55
Metals	17
Cl^-	5,192
Suspended solids	316,230
HC	98
Phenol	95
Dissolved solid	3,308
Na^+	4
SO_4^{2-}	4

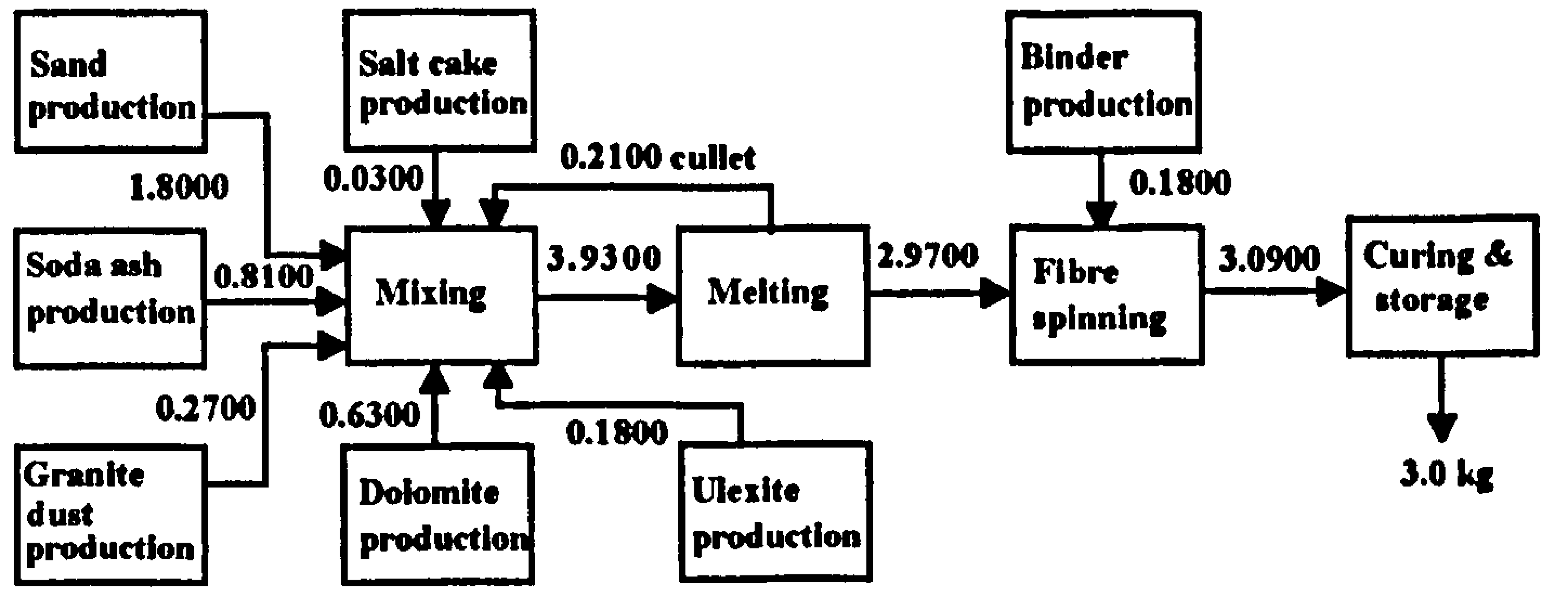
Air emissions	mg
Dust	27,803
CO	7,296
CO_2	12,861,400
SO_x	159,882
NO_x	202,331
HCl	1,269
F	106
HF	137
HC	50,992
Metals	84
CH_4	115,806

Solid waste	mg
Plastics	4
Organics	2
Mineral waste	7,981,800
Slags/ash	37,555
Industrial waste	94,580

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): rigid vehicle, 20 tonne payload, returning empty, average return distance 600 km

Appendix 42 Glass products

Production and road delivery of glass fibre wool 150 mm depth - per square metre



Schematic flow diagram for the production of 150 mm glass fibre wool
All flows are in kg per square metre

Gross inputs and outputs associated with the production and road delivery of 150 mm glass fibre wool / metre²
Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	24.73
Electricity - delivered	10.47
Oil fuels - production & delivery	1.09
Oil fuels - delivered	7.25
Oil fuels - feedstock	0.29
Other fuels - production & delivery	7.68
Other fuels - delivered	65.38
Other fuels - feedstock	2.92
Total energy	119.81

Raw materials	mg
Bauxite	44
Brine	1,280,900
Clay	15
Fe-Mn	21
Iron ore	6,409
Lead	9
Limestone	889,366
Met coal	2,636
Sand	1,800,000
Water	31,218,600
Wood	576
Phosphate	21
Sodium chloride	80
Ulexite	180,000
Granite	270,000
Dolomite	630,000
Nitrogen	193
Air	223,141
Sulphur	14,688

Air emissions	mg
Dust	18,867
CO	3,142
CO_2	6,045,700
SO_x	34,691
NO_x	60,772
NH_3	9
HCl	470
F	21
HF	22
HC	33,789
CHO	2
Organics	23
Metals	7
H_2SO_4	1
CH_4	107,325

Primary fuels	MJ
Coal	22.07
Oil	11.71
Gas	74.18
Hydro	0.41
Nuclear	8.61
Sulphur	0.14
Recovered	-0.15
Total fuels	116.96
Primary feedstocks	**MJ**
Coal	0.08
Oil	0.24
Gas	2.85
Total feedstocks	3.18
Total fuels & feedstocks	120.14

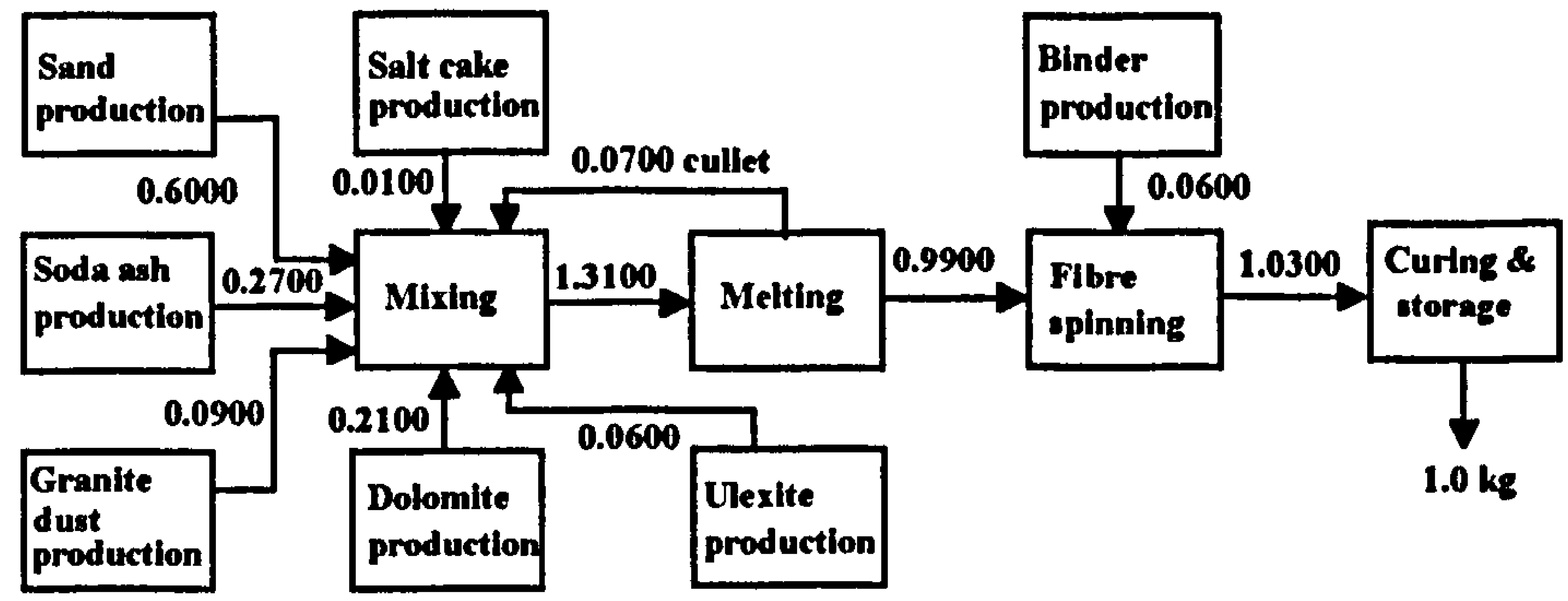
Water emissions	mg
COD	17
BOD	11
Salt	381
Acid	57
Metals	22
Cl^-	1,288
Dissolved organics	14
Suspended solids	115,603
Detergent/oil	1
HC	15
Phenol	11
Dissolved solid	857
Na^+	70
SO_4^{2-}	51
Phosphate/P_2O_5	6
Other organic	1

Solid waste	mg
Paper	114
Plastics	2
Metals	10
Other refuse	206
Mineral waste	1,892,300
Slags/ash	47,189
Industrial waste	5,367
Unregulated chemicals	28

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): rigid vehicle, 20 tonne payload, returning empty, average return distance 600 km

Appendix 43 Glass products

Production and road delivery of glass fibre wool, 50 mm depth, - per m²



Schematic flow diagram for the production of 50 mm glass fibre wool
All flows are in kg per square metre

Gross inputs and outputs associated with the production and road delivery of glass fibre wool, depth 50 mm, per m²

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	8.24
Electricity - delivered	3.49
Oil fuels - production & delivery	0.36
Oil fuels - delivered	2.42
Oil fuels - feedstock	0.10
Other fuels - production & delivery	2.56
Other fuels - delivered	21.79
Other fuels - feedstock	0.97
Total energy	39.94

Primary fuels	MJ
Coal	7.36
Oil	3.90
Gas	24.73
Hydro	0.14
Nuclear	2.87
Sulphur	0.05
Recovered	-0.05
Total fuels	38.99
Primary feedstocks	**MJ**
Coal	0.03
Oil	0.08
Gas	0.95
Total feedstocks	1.06
Total fuels & feedstocks	40.05

Raw materials	mg
Bauxite	15
Brine	426,964
Clay	5
Fe-Mn	7
Iron ore	2,136
Lead	3
Limestone	296,455
Met coal	879
Sand	600,007
Water	10,406,200
Wood	192
Phosphate	7
Sodium chloride	26
Ulexite	60,000
Granite	90,000
Dolomite	210,000
Nitrogen	64
Air	74,380
Sulphur	4,896

Water emissions	mg
COD	6
BOD	4
Salt	127
Acid	19
Metals	7
Cl^-	429
Dissolved organics	5
Suspended solids	38,534
HC	5
Phenol	4
Dissolved solid	286
Na^+	23
SO_4^{2-}	17
Phosphate/P_2O_5	2

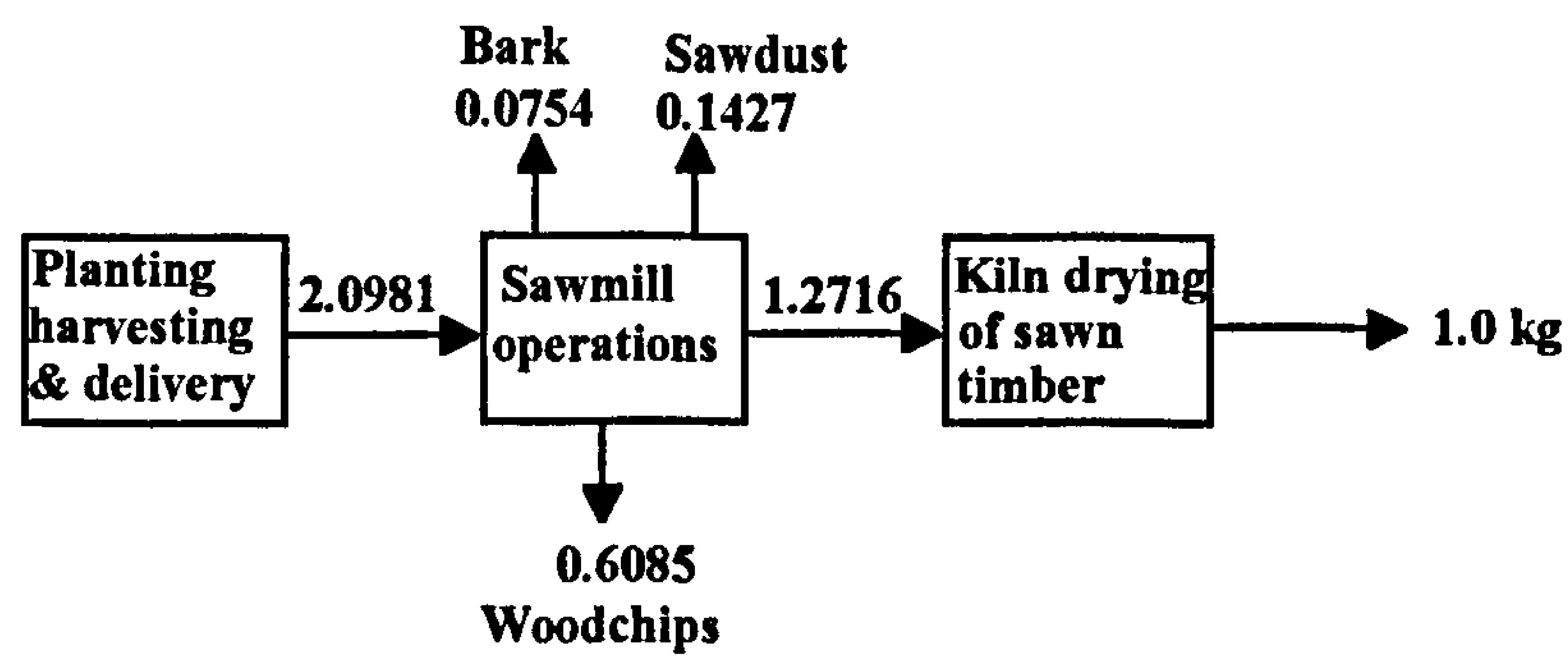
Air emissions	mg
Dust	6,289
CO	1,047
CO_2	2,015,200
SO_x	11,564
NO_x	20,257
NH_3	3
HCl	157
F	7
HF	8
HC	11,263
CHO	1
Organics	8
Metals	2
CH_4	35,775

Solid waste	mg
Paper	38
Metals	3
Other refuse	69
Mineral waste	630,769
Slags/ash	15,730
Industrial waste	1,789
Unregulated chemicals	9

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): rigid vehicle, 20 tonne payload, returning empty, average return distance 600 km

Appendix 44 Timber and timber products

Production and road delivery of kiln dried sawn timber (UK Sitka spruce) - per kg



Schematic flow diagram for the production of kiln dried sawn timber (UK Sitka spruce)
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of kiln dried sawn timber (UK Sitka spruce - per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.76
Electricity - delivered	0.32
Oil fuels - production & delivery	0.42
Oil fuels - delivered	2.89
Oil fuels - feedstock	0.01
Other fuels - delivered	0.01
Other fuels - feedstock	19.19
Total energy	23.60

Raw materials	mg
Bauxite	5
Brine	2
Fe-Mn	3
Iron ore	955
Lead	2
Limestone	340
Met coal	393
Water	187,728
Wood	1,271,600
Air	59
Sulphur	4

Air emissions	mg
Dust	507
CO	2,019
CO_2	287,273
SO_x	1,550
NO_x	2,784
HCl	13
HF	1
HC	842
CH_4	211

Primary fuels	MJ
Coal	0.69
Oil	3.25
Gas	0.17
Hydro	0.01
Nuclear	0.27
Total fuels	4.40
Primary feedstocks	**MJ**
Coal	0.01
Wood	19.18
Total feedstocks	19.19
Total fuels & feedstocks	23.59

Water emissions	mg
COD	3
BOD	3
Acid	2
Metals	1
Suspended solids	137
HC	3
Phenol	3

Solid waste	mg
Mineral waste	6,082
Slags/ash	1,509
Industrial waste	356

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicles returning empty
a) delivery of green timber to sawmill - 22 tonne payload, return distance 193 km
b) delivery of kiln dried sawn timber to customer - 23 tonne payload, return distance 322 km

Appendix 45 Timber and timber products

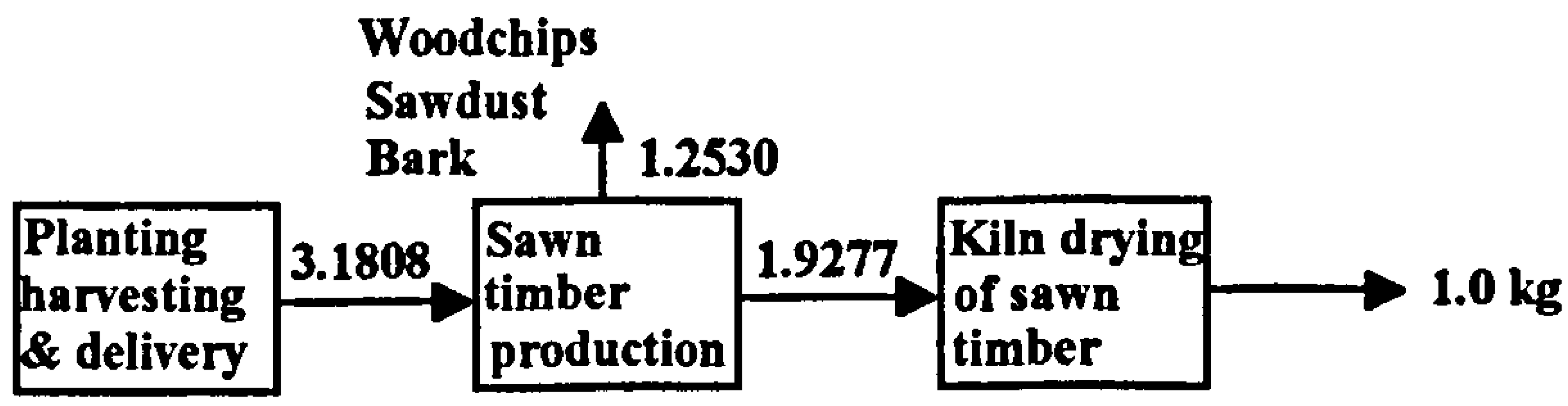
Production and road delivery of kiln dried sawn timber (UK Sitka spruce) lintels - per 1500 mm

Gross inputs and outputs associated with the production and road delivery of kiln dried timber lintels - per lintel
(derived from figures shown in Appendix 44) Totals may not agree because of rounding errors

		Lintel dimensions/weight	
Input/output	**Units**	**(100 x 143) mm**	**(125 x 143) mm**
Energy		**9.6216 kg**	**12.0270 kg**
Electricity - production & delivery	MJ	7.31	9.13
Electricity - delivered	MJ	3.09	3.87
Oil fuels - production & delivery	MJ	4.03	5.03
Oil fuels - delivered	MJ	27.85	34.81
Oil fuels - feedstock	MJ	0.08	0.10
Other fuels - production & delivery	MJ	0.01	0.02
Other fuels - delivered	MJ	0.09	0.11
Other fuels - feedstock	MJ	184.61	230.77
Total energy	MJ	227.07	283.84
Fuels			
Coal	MJ	6.66	8.33
Oil	MJ	31.31	39.13
Gas	MJ	1.68	2.09
Hydro	MJ	0.12	0.15
Nuclear	MJ	2.56	3.20
Total fuels	MJ	42.33	52.91
Feedstock			
Coal	MJ	0.12	0.15
Wood	MJ	184.5	230.63
Total feedstock	MJ	184.62	230.78
Total fuels & feedstock	MJ	226.95	283.69
Raw materials			
Barytes	mg	1	2
Bauxite	mg	53	66
Brine	mg	19	24
Fe-Mn	mg	30	38
Fluorspar	mg	0	1
Iron ore	mg	9,189	11,486
Lead	mg	15	19
Limestone	mg	3,270	4,088
Met coal	mg	3,780	4,725
Sand	mg	3	3
Water	mg	1,806,200	2,257,800
Wood	mg	12,234,800	15,293,600
Air	mg	572	715
Sulphur	mg	38	47
Air emissions			
Dust	mg	4,879	6,099
CO	mg	19,428	24,284
CO2	mg	2,764,000	3,455,000
SOx	mg	14,914	18,642
NOx	mg	26,790	33,488
HCl	mg	129	161
HF	mg	6	8
HC	mg	8,097	10
Lead	mg	2	2
Metals	mg	1	1
CH4	mg	2,030	2,538
Water emissions			
COD	mg	33	41
BOD	mg	29	36
Acid	mg	18	23
Metal ions	mg	6	7
Suspended solids	mg	1,314	1,643
Hydrocarbons	mg	30	38
Phenol	mg	29	36
Solid waste			
Plastics	mg	2	2
Organics	mg	0	1
Mineral waste	mg	58,523	73,154
Slags\ash	mg	14,519	18,148
Industrial waste	mg	3,424	4,280

Appendix 46 Timber and timber products

Production and road delivery of kiln dried sawn timber (imported Swedish Redwood) - per kg



Schematic flow diagram for the production of kiln dried sawn timber (Swedish Redwood))
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of kiln dried sawn timber (imported Swedish Redwood) - per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.36
Electricity - delivered	0.33
Oil fuels - production & delivery	0.90
Oil fuels - delivered	5.56
Oil fuels - feedstock	0.01
Other fuels - production & delivery	0.02
Other fuels - delivered	0.11
Other fuels - feedstock	16.95
Total energy	24.25

Raw materials	mg
Bauxite	9
Brine	3
Fe-Mn	5
Iron ore	1,598
Lead	3
Limestone	565
Met coal	657
Water	252,200
Wood	1,928,300
Air	99
Sulphur	7

Air emissions	mg
Dust	400
CO	3,787
CO_2	453,484
SO_x	1,908
NO_x	4,957
HCl	1
HC	1,681
CH_4	25

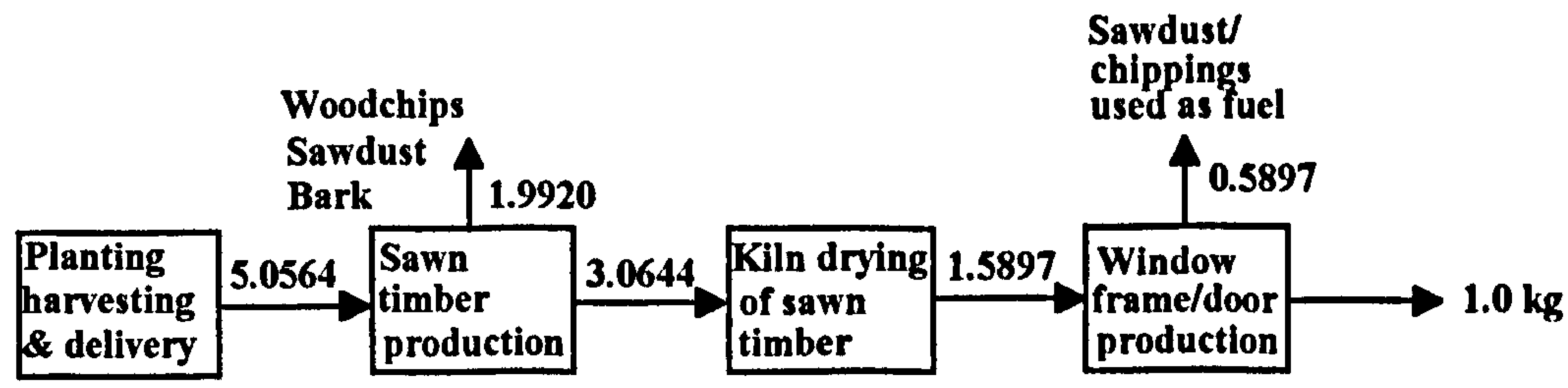
Primary fuels	MJ
Coal	0.15
Oil	6.21
Gas	0.26
Hydro	0.19
Nuclear	0.46
Total fuels	7.27
Primary feedstocks	**MJ**
Coal	0.02
Wood	16.94
Total feedstocks	16.96
Total fuels & feedstocks	24.23

Water emissions	mg
COD	7
BOD	2
Acid	6
Metals	1
Suspended solids	208
HC	56
Phenol	1

Solid waste	mg
Plastic containers	608
Plastics	2
Mineral waste	3,207
Slags/ash	443
Industrial waste	587

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicles returning empty
a) delivery of green timber to sawmill - 22 tonne payload, return distance 193 km
b) delivery of kiln dried sawn timber: (sawmill - seaport + UK seaport - customer), 23 tonne payload, return distance 579 km
Sea transport: 100,000 dwt bulk carrier fully loaded, distance one way 1,770 km

Production and road delivery of wooden window frames and doors - Swedish Redwood - per kg



Schematic flow diagram for the production of wooden window frames and doors -Swedish Redwood
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of wooden window frames/doors - Swedish Redwood) - per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.69
Electricity - delivered	0.57
Oil fuels - production & delivery	1.52
Oil fuels - delivered	9.42
Oil fuels - feedstock	0.04
Other fuels - production & delivery	0.04
Other fuels - delivered	10.18
Other fuels - feedstock	16.98
Total energy	39.43

Raw materials	mg
Bauxite	24
Brine	9
Fe-Mn	14
Iron ore	4,182
Lead	7
Limestone	1,479
Met coal	1,720
Water	454,480
Wood	3,065,400
Air	261
Sulphur	17

Air emissions	mg
Dust	727
CO	7,120
CO_2	1,920,300
SO_x	3,409
NO_x	10,600
HCl	4
HC	2,846
CH_4	91

Primary fuels	MJ
Coal	0.36
Oil	10.51
Gas	0.46
Hydro	0.31
Nuclear	0.77
Wood	9.99
Total fuels	22.39
Primary feedstocks	**MJ**
Coal	0.05
Wood	16.94
Total feedstocks	16.99
Total fuels & feedstocks	39.38

Water emissions	mg
COD	12
BOD	4
Acid	11
Metals	2
Suspended solids	544
HC	90
Phenol	2

Solid waste	mg
Plastic containers	967
Plastics	3
Mineral waste	8,154
Slags/ash	1,016
Industrial waste	1,004

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicle, 13.5 tonne payload, returning empty, average return distance 644 km

Appendix 48 Timber and timber products

Production and road delivery of kiln dried wooden window frames/doors & door frames - per item

Gross inputs and outputs associated with the production and road delivery of kiln dried wooden window frames/doors & door frames - per item (derived from figures shown in Appendix 47) Totals may not agree because of rounding errors			
		Overall window/ door frame dimensions/mm ; Wood input/kg	
Input/output	**Units**	**Casement window frame (1200 x 1200) mm : 17.5 kg**	**External kitchen door & door frame (762 x 1981) mm : 30.8 kg**
Energy			
Electricity - production & delivery	MJ	12.12	21.33
Electricity - delivered	MJ	9.90	17.42
Oil fuels - production & delivery	MJ	26.53	46.70
Oil fuels - delivered	MJ	164.83	290.10
Oil fuels - feedstock	MJ	0.66	1.17
Other fuels - production & delivery	MJ	0.64	1.13
Other fuels - delivered	MJ	178.22	313.67
Other fuels - feedstock	MJ	297.19	523.06
Total energy	MJ	690.10	1,214.57
Fuels			
Coal	MJ	6.22	10.94
Oil	MJ	183.97	323.79
Gas	MJ	7.97	14.02
Hydro	MJ	5.38	9.47
Nuclear	MJ	13.43	23.64
Wood	MJ	174.81	307.66
Total fuels	MJ	391.78	689.53
Feedstock			
Coal	MJ	0.94	1.66
Oil	MJ	0.01	0.01
Wood	MJ	296.39	521.64
Total feedstock	MJ	297.34	523.31
Total fuels & feedstock	MJ	689.12	1,212.84
Raw materials			
Barytes	mg	12	21
Bauxite	mg	423	744
Brine	mg	158	278
Fe-Mn	mg	240	422
Fluorspar	mg	8	14
Iron ore	mg	73,190	128,814
Lead	mg	128	226
Limestone	mg	25,890	45,566
Met coal	mg	30,106	52,987
Sand	mg	0	2
Water	mg	7,953,400	13,998,000
Wood	mg	53,645,200	94,415,500
Air	mg	4,565	8,034
Sulphur	mg	300	529
Air emissions			
Dust	mg	12,723	22,392
CO	mg	124,606	219,307
CO2	mg	33,604,900	59,144,600
SOx	mg	59,656	104,995
NOx	mg	185,501	326,481
HCl	mg	73	129
F	mg	2	4
HF	mg	3	6
HC	mg	49,801	87,649
Lead	mg	8	14
Metals	mg	8	13
CH4	mg	1,597	2,810
Water emissions			
COD	mg	204	359
BOD	mg	68	120
Acid	mg	186	327
Metal ions	mg	40	71
Suspended solids	mg	9,529	16,771
Hydrocarbons	mg	1,570	2,764
Phenol	mg	29	51
Solid waste			
Plastic containers	mg	16,919	29,778
Paper	mg	3	5
Plastics	mg	49	87
Metals	mg	11	19
Organics	mg	7	12
Mineral waste	mg	142,690	251,134
Slags\ash	mg	17,778	31,290
Industrial waste	mg	17,576	30,934

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicle, 13.5 tonne payload, returning empty, average return distance 644 km

Appendix 49 Metals and metal products

Production and road delivery of electrolytically refined copper metal - per kg [47]

Impure copper (anode) → Electrolysis of copper sulphate → Pure copper

Schematic flow diagram for the production of electrolytically refined copper

Gross inputs and outputs associated with the production and road delivery of electrolytically refined copper metal - per kg Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	14.66
Electricity - delivered	6.20
Oil fuels - production & delivery	4.97
Oil fuels - delivered	34.50
Oil fuels - feedstock	0.01
Other fuels - delivered	0.01
Other fuels - feedstock	0.01
Total energy	60.35

Raw materials	mg
Bauxite	12
Brine	3
Fe-Mn	7
Iron ore	2,081
Lead	2
Limestone	777
Met coal	856
Sand	5
Water	2,580,300
Copper	1,000,000
Air	125
Sulphur	8

Air emissions	mg
Dust	6,615
CO	1,700
CO_2	3,997,600
SO_x	66,715
NO_x	18,210
HCl	259
HF	13
HC	5,996
Metals	134
CH_4	3,824

Primary fuels	MJ
Coal	13.15
Oil	39.61
Gas	2.18
Hydro	0.24
Nuclear	5.14
Total fuels	60.32
Primary feedstocks	**MJ**
Coal	0.03
Total feedstocks	0.03
Total fuels & feedstocks	60.35

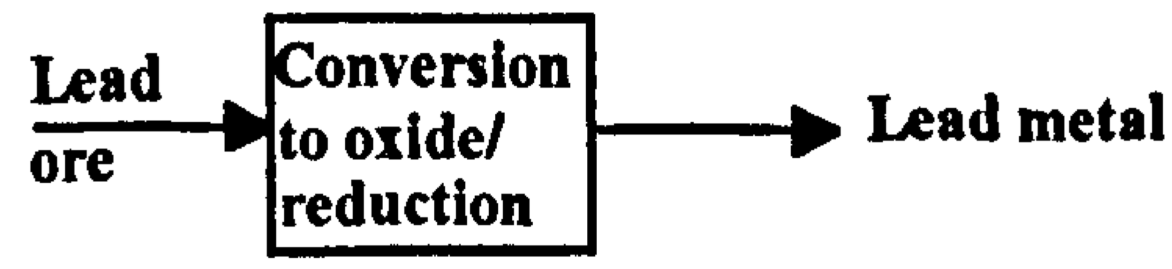
Water emissions	mg
COD	42
BOD	37
Acid	634
Metals	61
Suspended solids	550
HC	39
Phenol	37

Solid waste	mg
Mineral waste	3,093,600
Slags/ash	228,046
Industrial waste	4,333

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional):articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 50 Metals and metal products

Production and road delivery of lead metal - per kg [47]



Schematic flow diagram for the production of lead metal

Gross inputs and outputs associated with the production and road delivery of lead metal - per kg

Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	4.73
Electricity - delivered	2.00
Oil fuels - production & delivery	0.54
Oil fuels - delivered	3.73
Oil fuels - feedstock	0.01
Other fuels - production & delivery	4.04
Other fuels - delivered	35.91
Other fuels - feedstock	0.01
Total energy	50.96

Primary fuels	MJ
Coal	4.25
Oil	4.77
Gas	40.18
Hydro	0.08
Nuclear	1.66
Total fuels	50.94
Primary feedstocks	**MJ**
Coal	0.01
Total feedstocks	0.01
Total fuels & feedstocks	50.95

Raw materials	mg
Bauxite	5
Brine	2
Fe-Mn	3
Iron ore	928
Lead	1,000,000
Limestone	342
Met coal	382
Sand	2
Water	553,287
Air	57
Sulphur	4

Water emissions	mg
COD	5
BOD	4
Acid	11
Metals	3
Suspended solids	204
HC	5
Phenol	4

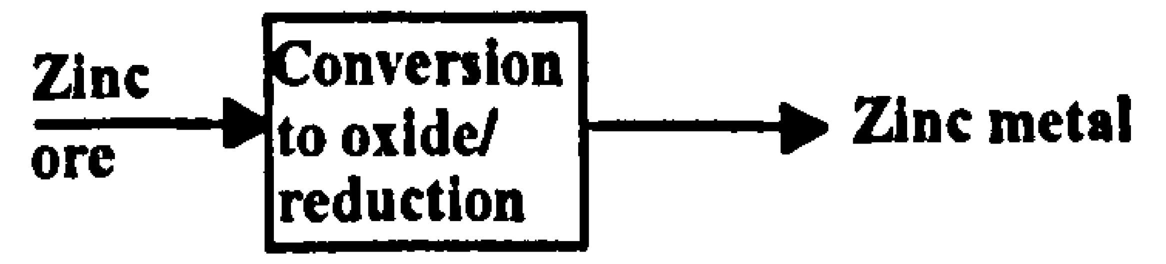
Solid waste	mg
Mineral waste	1,030,600
Slags/ash	9,084
Industrial waste	523

Air emissions	mg
Dust	4,941
CO	504
CO_2	2,570,100
SO_x	10,688
NO_x	29,989
HCl	84
HF	4
HC	17,895
Metals	4
CH_4	54,593

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional):articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 51 Metals and metal products

Production and road delivery of zinc metal - per kg [47]



Schematic flow diagram for the production of zinc metal

Gross inputs and outputs associated with the production and road delivery of zinc metal - per kg

Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	4.73
Electricity - delivered	2.00
Oil fuels - production & delivery	0.54
Oil fuels - delivered	3.73
Oil fuels - feedstock	0.01
Other fuels - production & delivery	4.04
Other fuels - delivered	35.91
Other fuels - feedstock	0.01
Total energy	50.96

Primary fuels	MJ
Coal	4.25
Oil	4.77
Gas	40.18
Hydro	0.08
Nuclear	1.66
Total fuels	50.94
Primary feedstocks	**MJ**
Coal	0.01
Total feedstocks	0.01
Total fuels & feedstocks	50.95

Raw materials	mg
Bauxite	5
Brine	2
Fe-Mn	3
Iron ore	928
Lead	1
Limestone	342
Met coal	382
Sand	2
Water	553,287
Zinc	1,000,000
Air	57
Sulphur	4

Water emissions	mg
COD	5
BOD	4
Acid	11
Metals	3
Suspended solids	204
HC	5
Phenol	4

Solid waste	mg
Mineral waste	1,030,600
Slags/ash	9,084
Industrial waste	523

Air emissions	mg
Dust	4,941
CO	504
CO_2	2,570,100
SO_x	10,688
NO_x	29,989
HCl	84
HF	4
HC	17,895
Metals	4
CH_4	54,593

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional):articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 52 Metals and metal products

Production and road delivery of cold rolled steel - per kg [47]

Iron ore → Blast furnace/ Basic oxygen furnace/ Cold rolling → Cold rolled steel

Schematic flow diagram for the production of cold rolled steel

Gross inputs and outputs associated with the production and road delivery of cold rolled steel - per kg

Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	6.99
Electricity - delivered	3.05
Oil fuels - production & delivery	0.36
Oil fuels - delivered	2.44
Oil fuels - feedstock	0.06
Other fuels - production & delivery	0.80
Other fuels - delivered	2.04
Other fuels - feedstock	16.90
Total energy	32.64

Raw materials	mg
Bauxite	7,587
Brine	956
Fe-Mn	4,299
Fluorspar	138
Iron ore	1,313,600
Lead	2
Limestone	464,589
Met coal	540,356
Sand	3
Water	18,281,400
Nitrogen	4
Air	76,187
Sulphur	5,016

Air emissions	mg
Dust	8,161
CO	2,256
CO_2	1,306,500
SO_x	113,249
NO_x	10,947
HCl	127
F	36
HF	6
HC	3,152
Metals	3
CH_4	9,158

Primary fuels	MJ
Coal	6.46
Oil	3.81
Gas	2.65
Hydro	0.26
Nuclear	2.50
Total fuels	15.67
Primary feedstocks	**MJ**
Coal	16.92
Oil	0.06
Total feedstocks	16.98
Total fuels & feedstocks	32.65

Water emissions	mg
COD	4
BOD	4
Acid	247
Metals	61
Cl^-	1
F^-	4
Suspended solids	169,237
HC	5
Phenol	4

Solid waste	mg
Mineral waste	1,951,800
Slags/ash	99,013
Industrial waste	426

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional):articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 53 Metals and metal products

Production and road delivery of I-section rolled steel joists, flange & web thickness 7 mm - per 1500 mm

Gross inputs and outputs associated with the production and road delivery of rolled steel joists - per 1500 mm
(derived from figures shown in Appendix 52) Totals may not agree because of rounding errors

Input/output	Units	RSJ size mm	
		100 x 143	125 x 143
Energy			
Electricity - production & delivery	MJ	190.82	219.84
Electricity - delivered	MJ	83.16	95.80
Oil fuels - production & delivery	MJ	9.85	11.34
Oil fuels - delivered	MJ	66.62	76.74
Oil fuels - feedstock	MJ	1.74	2.00
Other fuels - production & delivery	MJ	21.86	25.18
Other fuels - delivered	MJ	55.58	64.03
Other fuels - feedstock	MJ	461.13	531.24
Total energy	MJ	890.75	1,026.18
Fuels			
Coal	MJ	176.22	203.01
Oil	MJ	103.96	119.76
Gas	MJ	72.22	83.21
Hydro	MJ	6.98	8.04
Nuclear	MJ	68.35	78.74
Lignite	MJ	0.02	0.02
Sulphur	MJ	1.27	1.46
Recovered	MJ	-1.40	-1.62
Total fuels	MJ	427.6	492.62
Feedstock			
Coal	MJ	461.81	532.03
Oil	MJ	1.52	1.75
Gas	MJ	0.01	0.01
Total feedstock	MJ	463.34	533.79
Total fuels & feedstock	MJ	890.94	1,026.41
Raw materials			
Barytes	mg	5	6
Bauxite	mg	207,054	238,536
Brine	mg	26,083	30,048
$CaSO_4$	mg	3	3
Fe-Mn	mg	117,318	135,156
Fluorspar	mg	3,759	4,330
Iron ore	mg	35,849,600	41,300,500
Lead	mg	55	63
Limestone	mg	12,678,900	14,606,700
Met coal	mg	14,746,600	16,988,800
Sand	mg	89	108
Water	mg	498,908,600	574,766,200
Shale	mg	7	9
NaCl	mg	4	4
Nitrogen	mg	112	129
Air	mg	2,079,200	2,395,300
Sulphur	mg	136,881	157,702
Air emissions			
Dust	mg	222,727	256,591
CO	mg	61,570	70,932
CO2	mg	35,654,700	41,075,900
SOx	mg	3,090,600	3,560,600
NOx	mg	298,752	344,177
HCl	mg	3,454	3,980
F	mg	988	1,138
HF	mg	172	198
HC	mg	86,011	99,088
Metals	mg	82	95
CH4	mg	249,926	287,926
Water emissions			
COD	mg	120	138
BOD	mg	98	112
Salt	mg	1	1
Acid	mg	6,734	7,758
Metal ions	mg	1,664	1,918
Cl^-	mg	28	32
F^-	mg	106	123
Suspended solids	mg	4,618,600	5,320,800
Hydrocarbons	mg	125	144
Phenol	mg	98	112
Dissolved solids	mg	2	2
Na^+	mg	1	1
Solid waste			
Plastics	mg	5	6
Organics	mg	3	3
Mineral waste	mg	53,266,400	61,365,400
Slags\ash	mg	2,702,100	3,113,000
Industrial waste	mg	11,620	13,387

Appendix 54 Metals and metal products

Production and road delivery of pickled hot rolled steel coil - per kg [47]

Iron ore	→	Blast furnace/ Basic oxygen furnace/ Pickling	→ Pickled hot rolled steel coil

Schematic flow diagram for the production of pickled hot rolled steel coil

Gross inputs and outputs associated with the production and road delivery of pickled hot rolled steel coil - per kg

Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	5.93
Electricity - delivered	2.60
Oil fuels - production & delivery	0.36
Oil fuels - delivered	2.43
Oil fuels - feedstock	0.06
Other fuels - production & delivery	0.80
Other fuels - delivered	1.99
Other fuels - feedstock	16.90
Total energy	31.06

Primary fuels	MJ
Coal	5.51
Oil	3.65
Gas	2.56
Hydro	0.24
Nuclear	2.14
Total fuels	14.09
Primary feedstocks	**MJ**
Coal	16.92
Oil	0.06
Total feedstocks	16.98
Total fuels & feedstocks	31.07

Raw materials	mg
Bauxite	7,587
Brine	956
Fe-Mn	4,299
Fluorspar	138
Iron ore	1,313,600
Lead	2
Limestone	464,561
Met coal	540,327
Sand	3
Water	18,146,200
Nitrogen	4
Air	76,183
Sulphur	5,016

Water emissions	mg
COD	4
BOD	3
Acid	244
Metals	60
Cl^-	1
F^-	4
Suspended solids	169,209
HC	4
Phenol	3

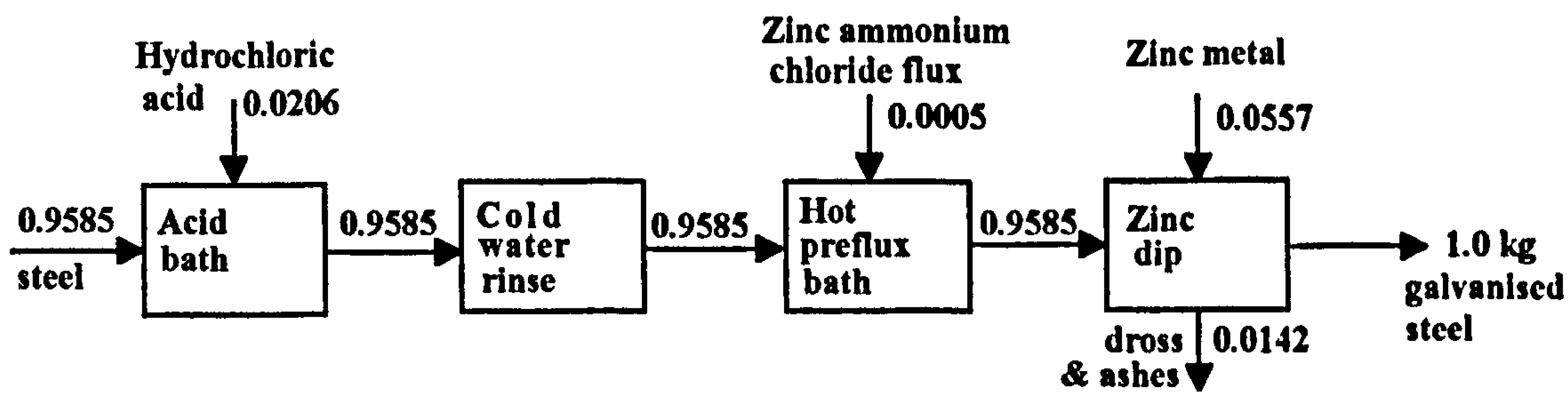
Solid waste	mg
Mineral waste	1,945,200
Slags/ash	97,004
Industrial waste	408

Air emissions	mg
Dust	7,714
CO	2,193
CO_2	1,216,300
SO_x	112,088
NO_x	10,554
HCl	108
F	36
HF	5
HC	3,066
Metals	3
CH_4	8,816

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional):articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 55 Metals and metal products

Production and road delivery of hot dip galvanised steel (610 g/m²) - general products - per kg



Schematic flow diagram for the production of hot dip galvanised steel products (610 g/sq.m)
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of hot dip galvanised steel products (610 g/m²) - per kg * Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	6.55
Electricity - delivered	2.86
Oil fuels - production & delivery	0.43
Oil fuels - delivered	2.90
Oil fuels - feedstock	0.07
Other fuels - production & delivery	1.19
Other fuels - delivered	5.46
Other fuels - feedstock	16.91
Total energy	36.36

Primary fuels	MJ
Coal	6.07
Oil	4.24
Gas	6.46
Hydro	0.25
Nuclear	2.35
Total fuels	19.37
Primary feedstocks	**MJ**
Coal	16.93
Oil	0.06
Total feedstocks	16.99
Total fuels & feedstocks	36.35

Raw materials	mg
Bauxite	7,591
Brine	12,000
Fe-Mn	4,301
Fluorspar	138
Iron ore	1,314,300
Lead	3
Limestone	464,823
Met coal	540,630
Sand	3
Water	18,455,000
Zinc	55,670
Nitrogen	6
Air	125,742
Sulphur	8,279

Water emissions	mg
COD	5
BOD	4
Acid	246
Metals	61
Cl^-	12
F^-	4
Suspended solids	169,316
HC	5
Phenol	4

Solid waste	mg
Mineral waste	2,005,800
Slags/ash	112,421
Industrial waste	474

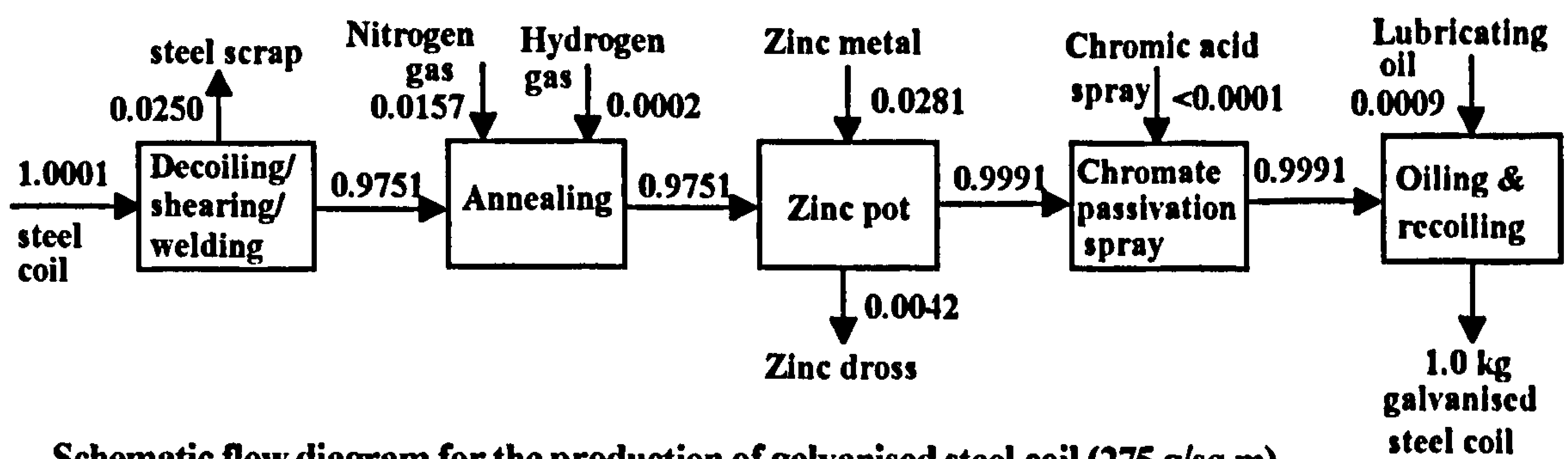
Air emissions	mg
Dust	8,298
CO	2,407
CO_2	1,485,800
SO_x	113,201
NO_x	13,664
HCl	119
F	36
HF	6
HC	4,852
Metals	3
CH_4	14,141

* Input of zinc ammonium chloride omitted for lack of production data

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicle, 20 tonne payload, returning with full load, average return distance 322 km

Appendix 56 Metals and metal products

Production and road delivery of galvanised steel coil (275 g/m²) - suitable for use in combined lintel production - per kg



Schematic flow diagram for the production of galvanised steel coil (275 g/sq.m)
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of galvanised steel coil (275 g/m²) - per kg
Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	7.67
Electricity - delivered	3.33
Oil fuels - production & delivery	0.40
Oil fuels - delivered	2.73
Oil fuels - feedstock	0.07
Other fuels - production & delivery	1.02
Other fuels - delivered	4.03
Other fuels - feedstock	16.90
Total energy	36.17

Raw materials	mg
Bauxite	7,591
Brine	959
Fe-Mn	4,301
Fluorspar	138
Iron ore	1,314,300
Lead	3
Limestone	464,819
Met coal	540,613
Sand	4
Water	18,344,200
Zinc	28,099
Nitrogen	15,739
Air	76,238
Sulphur	5,019
Chromium	1

Air emissions	mg
Dust	8,615
CO	2,408
CO_2	1,484,800
SO_x	114,225
NO_x	12,817
HCl	138
F	36
HF	7
HC	4,188
Metals	3
CH_4	12,242

Primary fuels	MJ
Coal	7.07
Oil	4.22
Gas	4.85
Hydro	0.27
Nuclear	2.74
Other	0.04
Total fuels	19.18
Primary feedstocks	**MJ**
Coal	16.93
Oil	0.06
Total feedstocks	16.99
Total fuels & feedstocks	36.17

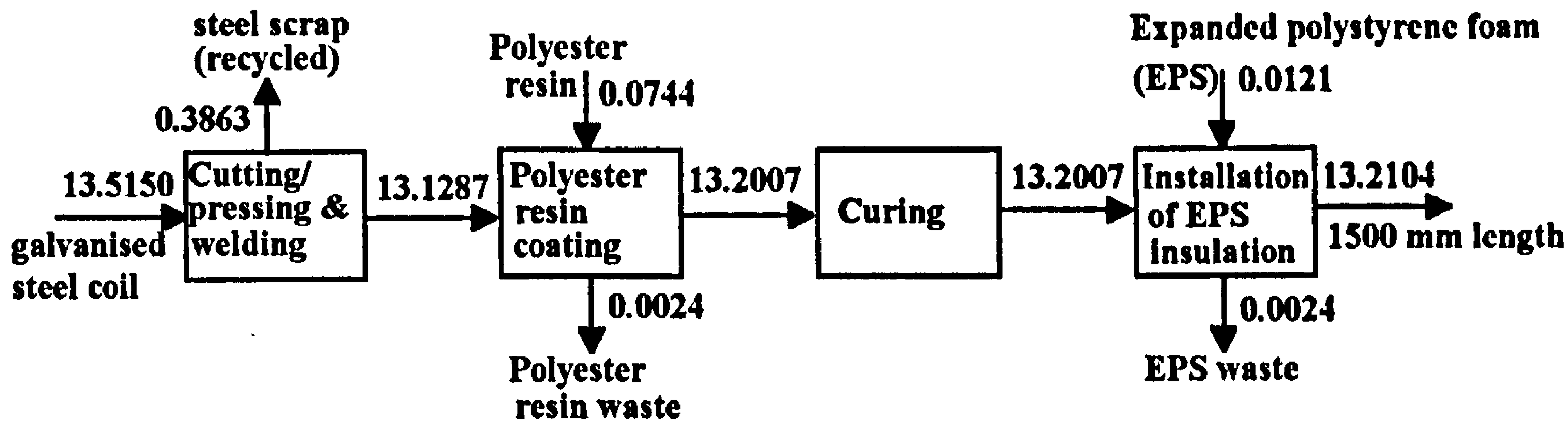
Water emissions	mg
COD	5
BOD	4
Acid	248
Metals	61
Cl^-	2
F^-	4
Suspended solids	169,331
HC	6
Phenol	4

Solid waste	mg
Mineral waste	1,985,000
Slags/ash	104,498
Industrial waste	475

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicle, 23.5 tonne payload, returning empty, average return distance 290 km

Appendix 57 Metals and metal products

Production and road delivery of insulated galvanised steel combined lintels - per 1500 mm length
(base 270 mm., inner leaf 125 mm., outer leaf 95 mm., cavity 50 mm., web 143 mm)



Schematic flow diagram for the production of a 1500 mm length galvanised steel combined lintel
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of insulated galvanised steel box lintels- per 1500 mm length Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	123.26
Electricity - delivered	53.35
Oil fuels - production & delivery	8.14
Oil fuels - delivered	52.77
Oil fuels - feedstock	3.82
Other fuels - production & delivery	15.04
Other fuels - delivered	64.19
Other fuels - feedstock	229.72
Total energy	550.28

Primary fuels	MJ
Coal	112.95
Oil	77.34
Gas	78.05
Hydro	3.93
Nuclear	43.86
Lignite	0.01
Other	0.48
Sulphur	0.63
Recovered	-0.70
Total fuels	316.55
Primary feedstocks	**MJ**
Coal	228.84
Oil	3.65
Gas	1.25
Total feedstocks	233.74
Total fuels & feedstocks	550.29

Raw materials	mg
Barytes	4
Bauxite	102,641
Brine	12,969
$CaSO_4$	2
Fe-Mn	58,133
Fluorspar	1,863
Iron ore	17,764,000
Lead	39
Limestone	6,282,800
Met coal	7,307,100
Sand	56
Water	251,507,700
Zinc	379,758
Shale	5
NaCl	521
Nitrogen	212,706
Air	1,030,500
Sulphur	67,843
Chromium	16

Water emissions	mg
COD	352
BOD	147
Acid	3,414
Metals	867
NH_4^+	5
Cl^-	88
F	53
Dissolved organics	971
Suspended solids	2,289,100
Detergent/oil	5
HC	137
Phenol	71
Dissolved solids	48
Na^+	112
SO_4^{2-}	3

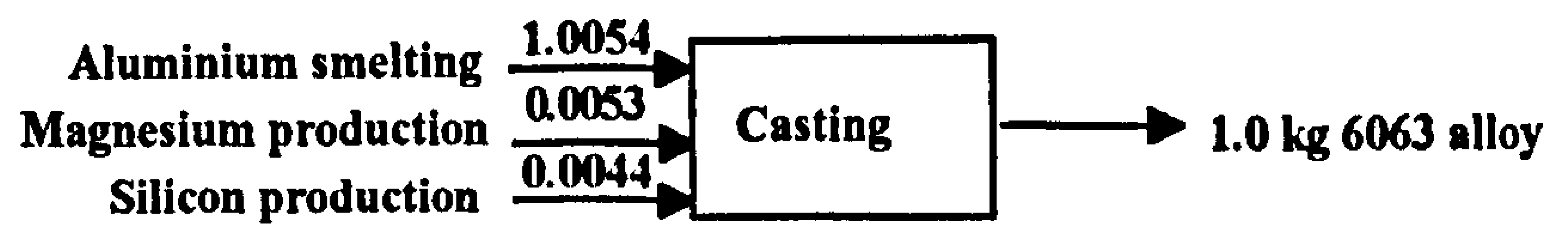
Air emissions	mg
Dust	126,423
CO	45,674
CO_2	23,455,500
SO_x	1,571,400
NO_x	201,358
HCl	2,215
F	490
HF	110
HC	69,146
Organics	691
Metals	46
Methane	183,073
Pentane	1,033

Solid waste	mg
Plastics	4
Organics	2
Mineral waste	26,949,500
Slags/ash	1,449,300
Industrial waste	13,610
Regulated chemicals	10
Unregulated chemicals	209

Packaging & delivery: Bulk delivery, no packaging
Road transport:articulated vehicle, 15 tonne payload, returning empty, average return distance 1127 km

Appendix 58 Metals and metal products

Production and rail delivery of 6063 cast aluminium alloy ingot-per kg[47]



Schematic flow diagram for the production of 6063 cast aluminium alloy ingot
All flows are in kg

Gross inputs and outputs associated with the production and rail delivery of 6063 cast aluminum alloy ingot- per kg

Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	25.85
Electricity - delivered	56.54
Oil fuels - production & delivery	7.03
Oil fuels - delivered	21.01
Oil fuels - feedstock	28.49
Other fuels - production & delivery	1.51
Other fuels - delivered	13.29
Other fuels - feedstock	0.04
Total energy	153.74

Primary fuels	MJ
Coal	7.78
Oil	26.49
Gas	17.38
Hydro	70.62
Nuclear	2.98
Sulphur	0.28
Recovered	-0.31
Total fuels	125.22
Primary feedstocks	**MJ**
Coal	0.05
Oil	28.48
Total feedstocks	28.53
Total fuels & feedstocks	153.75

Raw materials	mg
Bauxite	3,910,500
Brine	491,716
$CaSO_4$	9
Fe-Mn	13
Fluorspar	71,030
Iron ore	3,903
Lead	3
Limestone	20,227
Magnesium	5,278
Met coal	1,606
Sand	9,666
Water	41,687,900
Shale	26
NaCl	19
Nitrogen	570
Air	454,018
Sulphur	29,892

Water emissions	mg
COD	57
BOD	51
Salt	3
Acid	70
Metals	20
Cl^-	502
F^-	2,011
Suspended solids	378,480
HC	52
Phenol	51
Dissolved solids	9
Na^+	3
SO_4^{2-}	1

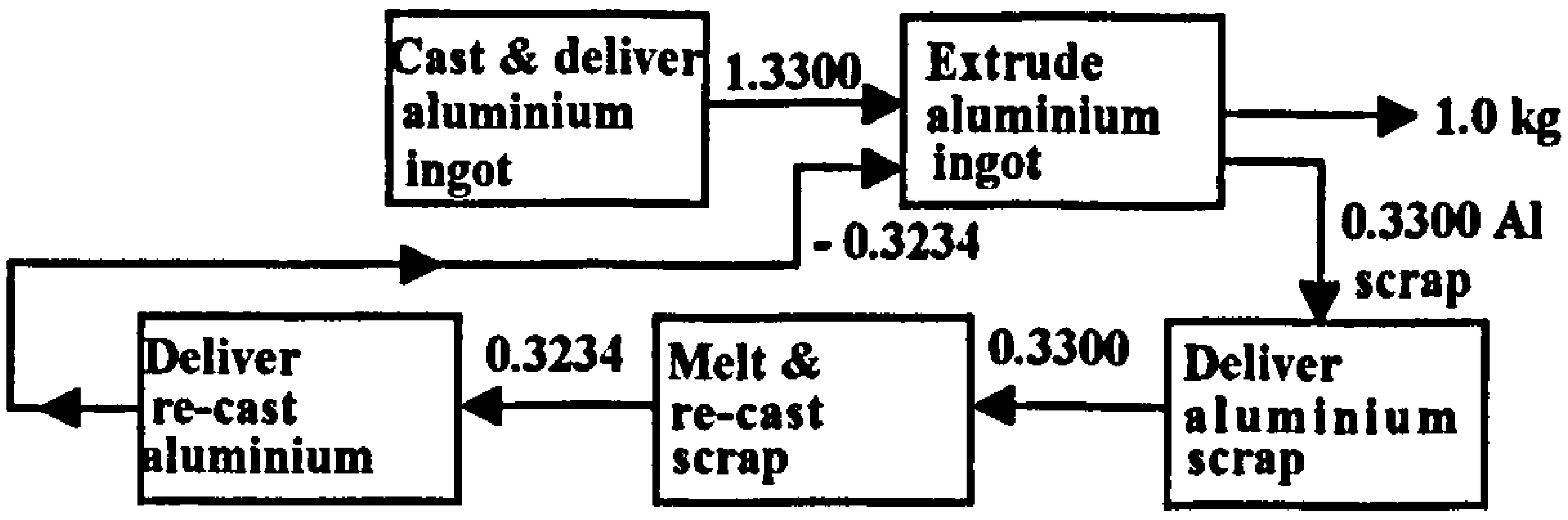
Air emissions	
Dust	26,223
CO	515,380
CO_2	4,349,600
SO_x	42,772
NO_x	23,477
HCl	150
F	5,662
HF	8
HC	11,678
Metals	21
CH_4	21,903

Solid waste	mg
Mineral waste	6,050,900
Slags/ash	93,924
Industrial waste	6,401

Packaging & delivery: Bulk delivery, no packaging
Rail freight transport: single journey - distance 483 km

Appendix 59 Metals and metal products

Production and road delivery of extruded 6063 aluminium alloy ingot-per kg



Schematic flow diagram for the production of extruded 6063 aluminium alloy ingot
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of extruded 6063 aluminum alloy ingot-per kg Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	34.56
Electricity - delivered	60.52
Oil fuels - production & delivery	7.45
Oil fuels - delivered	23.77
Oil fuels - feedstock	28.70
Other fuels - production & delivery	1.67
Other fuels - delivered	14.72
Other fuels - feedstock	0.07
Total energy	171.46

Primary fuels	MJ
Coal	15.44
Oil	30.71
Gas	19.37
Hydro	71.22
Nuclear	5.96
Sulphur	0.28
Recovered	-0.31
Total fuels	142.68
Primary feedstocks	**MJ**
Coal	0.09
Oil	28.66
Total feedstocks	28.75
Total fuels & feedstocks	171.43

Raw materials	mg
Bauxite	3,936,400
Brine	494,967
$CaSO_4$	9
Fe-Mn	22
Fluorspar	71,499
Iron ore	6,873
Lead	7
Limestone	21,425
Magnesium	5,313
Met coal	2,827
Sand	9,732
Water	42,809,500
Shale	26
NaCl	19
Nitrogen	574
Air	457,196
Sulphur	30,101

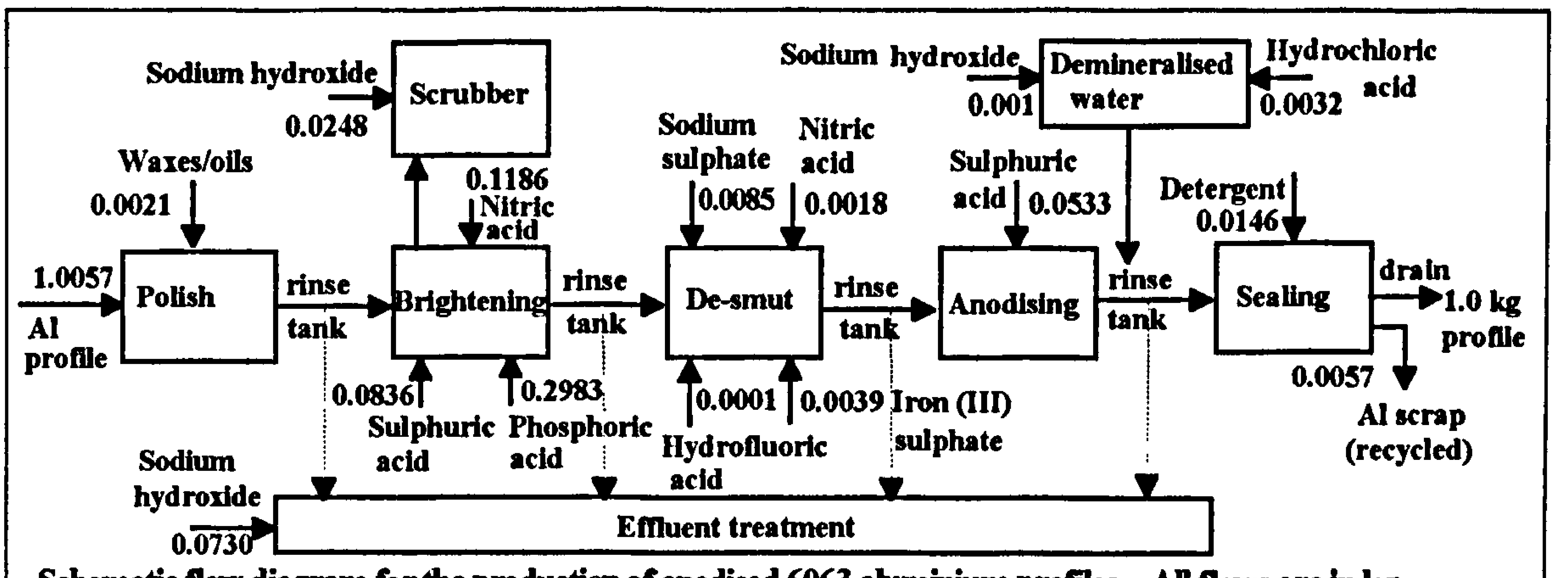
Water emissions	mg
COD	62
BOD	55
Salt	3
Acid	90
Metals	26
Cl^-	505
F^-	2,024
Suspended solids	381,508
HC	57
Phenol	55
Dissolved solids	9
Na^+	3
SO_4^{2-}	1

Air emissions	
Dust	49,942
CO	519,906
CO_2	5,353,700
SO_x	55,206
NO_x	28,885
HCl	301
F	5,699
HF	15
HC	13,373
Metals	24
CH_4	26,218

Solid waste	mg
Mineral waste	6,147,300
Slags/ash	110,826
Industrial waste	6,888

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Production and road delivery of anodised 6063 aluminium profiles-per kg



Schematic flow diagram for the production of anodised 6063 aluminium profiles. - All flows are in kg

Gross inputs and outputs associated with the production and road delivery of anodised 6063 aluminum profiles - per kg Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	65.33
Electricity - delivered	73.56
Oil fuels - production & delivery	7.70
Oil fuels - delivered	24.89
Oil fuels - feedstock	29.31
Other fuels - production & delivery	2.82
Other fuels - delivered	21.53
Other fuels - feedstock	0.98
Total energy	226.12

Primary fuels	MJ
Coal	46.40
Oil	36.39
Gas	24.63
Hydro	71.75
Nuclear	16.69
Sulphur	0.75
Recovered	-0.83
Total fuels	195.78
Primary feedstocks	**MJ**
Coal	0.15
Oil	29.27
Gas	0.88
Total feedstocks	30.30
Total fuels & feedstocks	226.08

Raw materials	mg
Bauxite	3,937,100
Brine	524,472
$CaSO_4$	10
Fe-Mn	33
Fluorspar	71,693
Iron ore	11,366
Lead	8
Limestone	23,654
Magnesium	5,314
Met coal	4,670
Sand	308,017
Water	129,257,300
Phosphate	745,625
Shale	28
NaCl	43,680
Nitrogen	606
Air	2,809,700
Sulphur	80,886

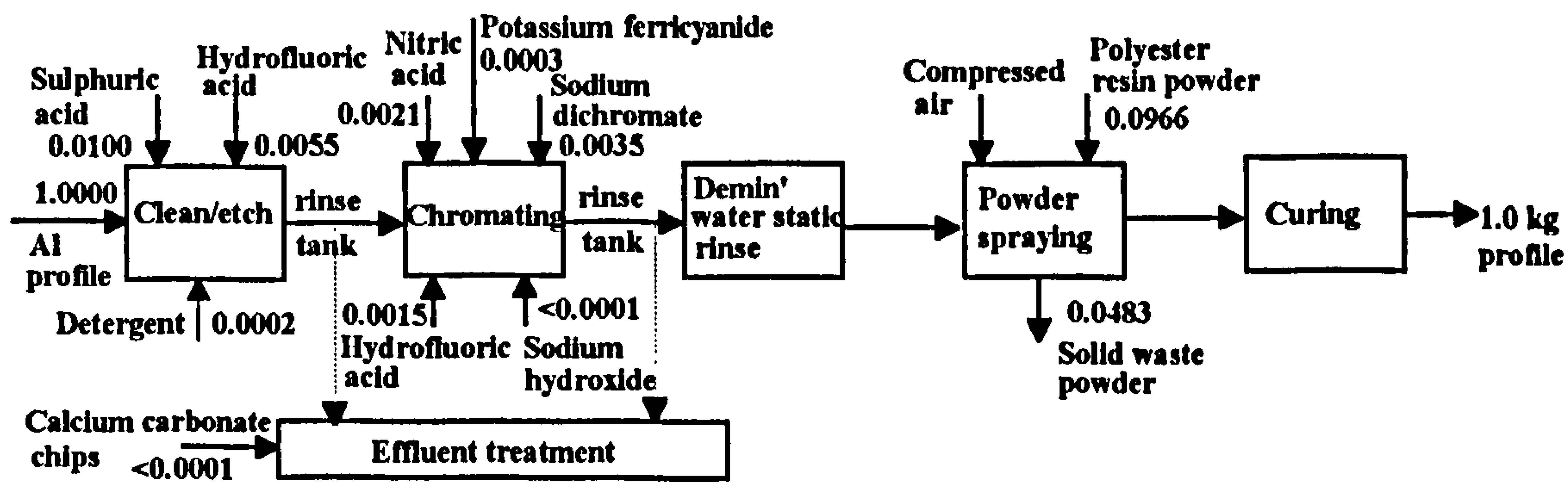
Water emissions	mg
COD	88
BOD	61
Salt	3
Acid	195
Metals	57
Cl^-	2,681
F^-	2,024
Suspended solids	458,084
HC	67
Phenol	61
Dissolved solids	13
Na^+	307
SO_4^{2-}	290
Al^{3+}	317

Air emissions	mg
Dust	65,525
CO	522,303
CO_2	8,608,500
SO_x	95,101
NO_x	43,880
NH_3	3
HCl	916
F	5,700
HF	44
HC	17,521
Metals	29
CH_4	41,111
Hydrogen	251

Solid waste	mg
Mineral waste	6,546,700
Slags/ash	245,587
Industrial waste	134,116
Regulated chemicals	1
Unregulated chemicals	518

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Production and road delivery of polyester resin powder coated 6063 aluminium profiles-per kg Al



Schematic flow diagram for the production of polyester resin powder coated 6063 aluminium profiles
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of polyester resin powder coated 6063 aluminum profiles- per kg * Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	43.83
Electricity - delivered	64.45
Oil fuels - production & delivery	7.96
Oil fuels - delivered	25.30
Oil fuels - feedstock	30.74
Other fuels - production & delivery	3.37
Other fuels - delivered	29.02
Other fuels - feedstock	0.90
Total energy	205.56

Raw materials	mg
Barytes	3
Bauxite	3,936,400
Brine	527,534
$CaSO_4$	9
Fe-Mn	35
Fluorspar	87,301
Iron ore	10,735
Lead	27
Limestone	29,933
Magnesium	5,313
Met coal	4,403
Rutile	40,195
Sand	9,740
Water	80,893,400
Shale	27
NaCl	341
Nitrogen	703
Air	609,447
Sulphur	40,125
Chromium	1,290

Air emissions	mg
Dust	55,048
CO	522,217
CO_2	7,013,000
SO_x	67,052
NO_x	44,053
HCl	463
F	5,699
HF	23
HC	22,969
Organics	566
Metals	26
CH_4	48,639

* Input of potassium ferricyanide omitted for lack of data

Primary fuels	MJ
Coal	23.72
Oil	33.87
Gas	35.79
Hydro	71.38
Nuclear	9.19
Sulphur	0.37
Recovered	-0.41
Total fuels	173.90
Primary feedstocks	**MJ**
Coal	0.14
Oil	30.69
Gas	0.78
Total feedstocks	31.61
Total fuels & feedstocks	205.51

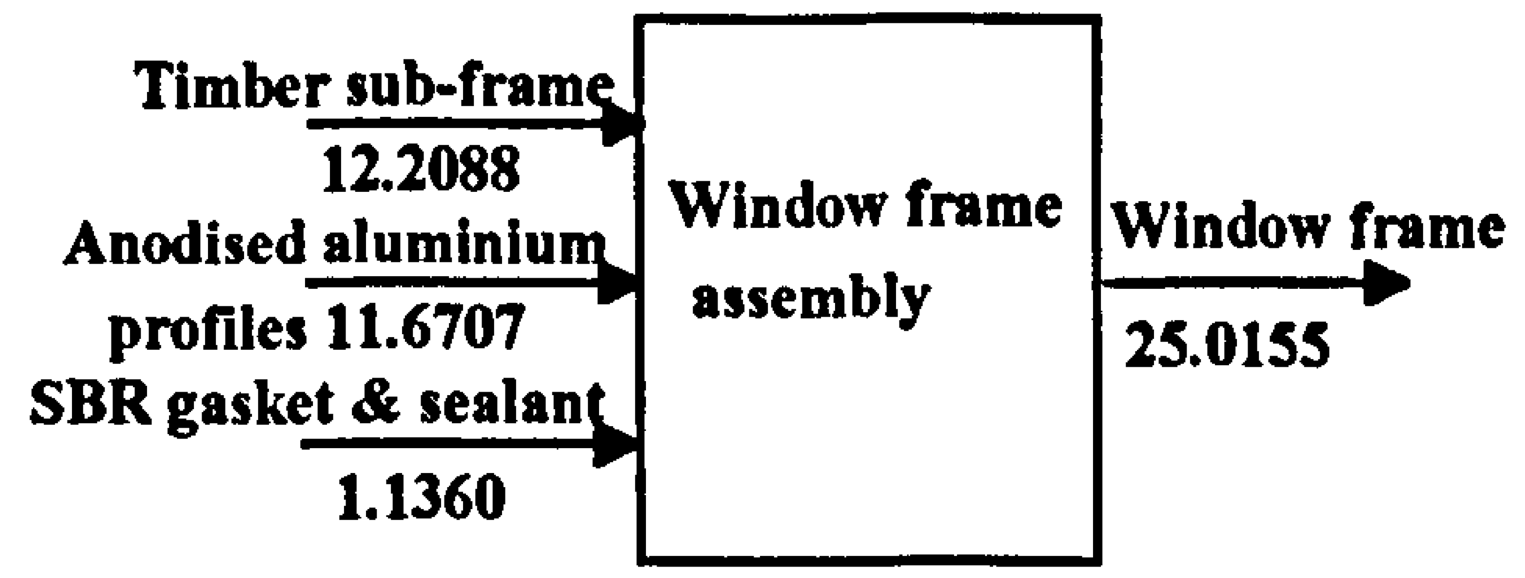
Water emissions	mg
COD	254
BOD	118
Salt	4
Acid	121
Metals	40
Cl^-	584
F	2,024
Dissolved organics	791
Suspended solids	388,518
Detergent/oil	1
HC	85
Phenol	57
Dissolved solids	47
Na^+	97
SO_4^{2-}	5

Solid waste	mg
Plastics	3
Organics	1
Mineral waste	6,266,700
Slags/ash	128,468
Industrial waste	78,574
Regulated chemicals	8
Unregulated chemicals	98

Packaging & delivery: Bulk delivery, no packaging
Road transport: rigid vehicle, 500 kg tonne payload, returning empty, average return distance 80 km

Appendix 62 Metals and metal products

Production and road delivery of anodised aluminium casement window frames (1200 mm x 1200 mm) -per frame



Schematic flow diagram for the production of anodised aluminium casement window frames (1200mm x 1200mm) opening. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of anodised aluminium casement window frames (1200mm x 1200mm) opening - per frame Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	787.98
Electricity - delivered	872.57
Oil fuels - production & delivery	120.38
Oil fuels - delivered	431.11
Oil fuels - feedstock	401.74
Other fuels - production & delivery	35.36
Other fuels - delivered	393.83
Other fuels - feedstock	218.84
Total energy	3,261.14

Primary fuels	MJ
Coal	561.42
Oil	588.38
Gas	317.29
Hydro	841.35
Nuclear	210.18
Lignite	0.05
Wood	121.95
Sulphur	8.79
Recovered	-9.75
Total fuels	2,639.68

Primary feedstocks	MJ
Coal	2.46
Oil	400.78
Gas	10.33
Wood	206.77
Total feedstocks	620.34
Total fuels & feedstocks	3,260.02

Raw materials	mg
Barytes	18
Bauxite	45,949,100
Brine	6,785,200
$CaSO_4$	115
Fe-Mn	574
Fluorspar	836,708
Iron ore	190,476
Lead	198
Limestone	296,564
Magnesium	62,014
Met coal	78,283
Sand	3,594,800
Water	1,600,900,000
Wood	37,425,300
Phosphate	8,701,900
Shale	324
NaCl	509,772
Nitrogen	7,080
Air	32,878,200
Sulphur	949,752

Water emissions	mg
COD	1,270
BOD	845
Salt	33
Acid	2,441
Metals	711
Cl^-	31,957
F^-	23,626
Suspended solids	5,354,000
HC	1,969
Phenol	815
Dissolved solids	154
Na^+	3,582
SO_4^{2-}	3,380
Al^{3+}	3,700

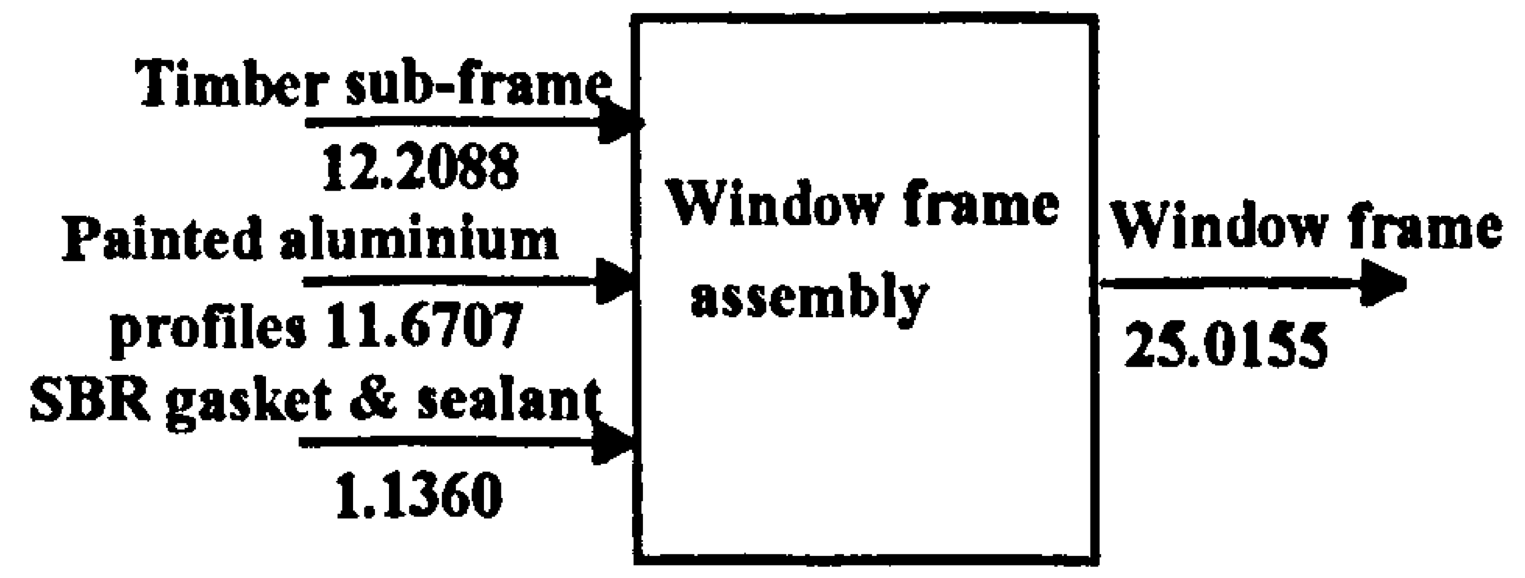
Air emissions	mg
Dust	783,100
CO	6,184,800
CO_2	128,761,200
SO_x	1,206,000
NO_x	674,459
NH_3	41
CL_2	1
HCl	11,050
F	66,526
HF	534
HC	256,953
Lead	5
Metals	367
CH_4	511,581
Hydrogen	2,929

Solid waste	mg
Plastic containers	11,804
Paper	2
Plastics	45
Metals	7
Organics	11
Mineral waste	76,620,700
Slags/ash	2,911,800
Industrial waste	1,587,800
Regulated chemicals	17
Unregulated chemicals	6,048

Packaging & delivery: Bulk delivery, no packaging
Road transport: rigid vehicle, 5.5 tonne payload, returning empty, average return distance 32 km

Appendix 63 Metals and metal products

Production and road delivery of powder painted aluminium casement window frames (1200 mm x 1200 mm) - per frame



Schematic flow diagram for the production of painted aluminium casement window frames (1200mm x 1200mm) opening. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of anodised aluminium casement window frames (1200mm x 1200mm) opening - per frame Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	536.97
Electricity - delivered	766.26
Oil fuels - production & delivery	123.41
Oil fuels - delivered	435.89
Oil fuels - feedstock	418.42
Other fuels - production & delivery	41.71
Other fuels - delivered	480.63
Other fuels - feedstock	217.85
Total energy	3,021.14

Primary fuels	MJ
Coal	296.69
Oil	558.97
Gas	447.51
Hydro	837.04
Nuclear	122.62
Lignite	0.03
Wood	121.95
Sulphur	4.39
Recovered	-4.86
Total fuels	2,384.34

Primary feedstocks	MJ
Coal	2.36
Oil	417.30
Gas	9.15
Wood	206.77
Total feedstocks	635.59
Total fuels & feedstocks	3,019.92

Raw materials	mg
Barytes	39
Bauxite	45,940,800
Brine	6,821,000
$CaSO_4$	110
Fe-Mn	598
Fluorspar	1,018,900
Iron ore	183,107
Lead	417
Limestone	369,835
Magnesium	62,004
Met coal	75,174
Rutile	469,104
Sand	113,683
Water	1,036,400,000
Wood	37,425,300
Shale	311
NaCl	3,985
Nitrogen	8,210
Air	7,200,100
Sulphur	474,035
Chromium	15,059

Water emissions	mg
COD	3,207
BOD	1,514
Salt	49
Acid	1,587
Metals	505
Cl^-	7,483
F	23,622
Dissolved organics	9,230
Suspended solids	4,542,100
Detergent/oil	14
HC	2,176
Phenol	776
Dissolved solids	549
Na^+	1,138
SO_4^{2-}	64

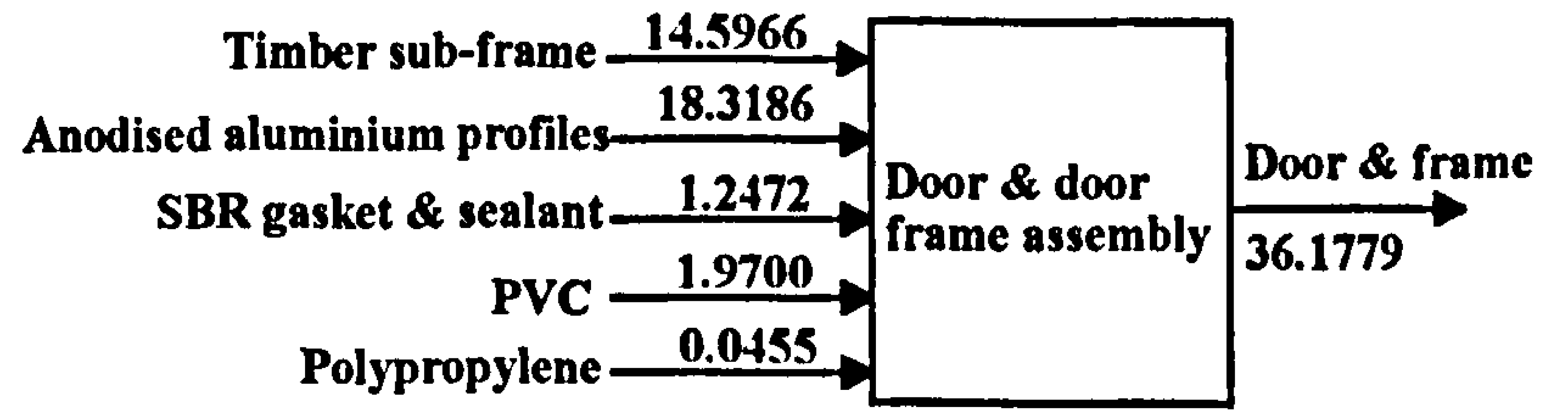
Air emissions	mg
Dust	660,828
CO	6,183,800
CO_2	110,139,600
SO_x	878,615
NO_x	676,479
NH_3	1
CL_2	1
HCl	5,759
F	66,514
HF	289
HC	320,536
Organics	6,603
Lead	5
Metals	337
CH_4	599,430

Solid waste	mg
Plastic containers	11,804
Paper	2
Plastics	67
Metals	7
Organics	23
Mineral waste	73,352,100
Slags/ash	1,545,000
Industrial waste	939,611
Regulated chemicals	92
Unregulated chemicals	1,142

Packaging & delivery: Bulk delivery, no packaging
Road transport: rigid vehicle, 5.5 tonne payload, returning empty, average return distance 32 km

Appendix 64 Metals and metal products

Production and road delivery of anodised aluminium external kitchen door and frame (762 mm x 1981 mm) -per door/frame



Schematic flow diagram for the production of anodised aluminium door & frame (762mm x 1981mm) opening. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of anodised aluminium external kitchen door and frame, (762mm x 1981mm) opening - per door/frame Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	1,270.48
Electricity - delivered	1,382.60
Oil fuels - production & delivery	182.59
Oil fuels - delivered	631.18
Oil fuels - feedstock	636.95
Other fuels - production & delivery	60.18
Other fuels - delivered	589.17
Other fuels - feedstock	290.18
Total energy	5,043.34

Raw materials	mg
Barytes	84,196
Bauxite	72,123,300
Brine	10,429,100
$CaSO_4$	180
Chalk	94,919
Clay	71
Fe-Mn	865
Fluorspar	1,313,300
Iron ore	288,401
Lead	290
Limestone	503,565
Magnesium	97,338
Met coal	118,279
Rutile	89,098
Sand	5,644,000
Water	2,519,300,000
Wood	44,746,500
Phosphate	13,658,800
Shale	510
NaCl	1,868,500
Nitrogen	11,117
Air	51,709,000
Sulphur	1,497,500

Air emissions	mg
Dust	1,241,100
CO	9,681,900
CO_2	197,212,800
SO_x	1,913,000
NO_x	1,036,200
NH_3	67
CL_2	4
HCl	18,102
F	104,421
HF	856
HC	418,044
Lead	6
Metals	573
CH_4	803,020
Hydrogen	4,598
Organo-chlorine	807

Primary fuels	MJ
Coal	912.83
Oil	878.62
Gas	520.09
Hydro	1,319.82
Nuclear	339.17
Lignite	0.08
Wood	145.81
Sulphur	13.87
Recovered	-15.37
Total fuels	4,114.91
Primary feedstocks	**MJ**
Coal	3.73
Oil	635.57
Gas	40.34
Wood	247.23
Total feedstocks	926.86
Total fuels & feedstocks	5,041.78

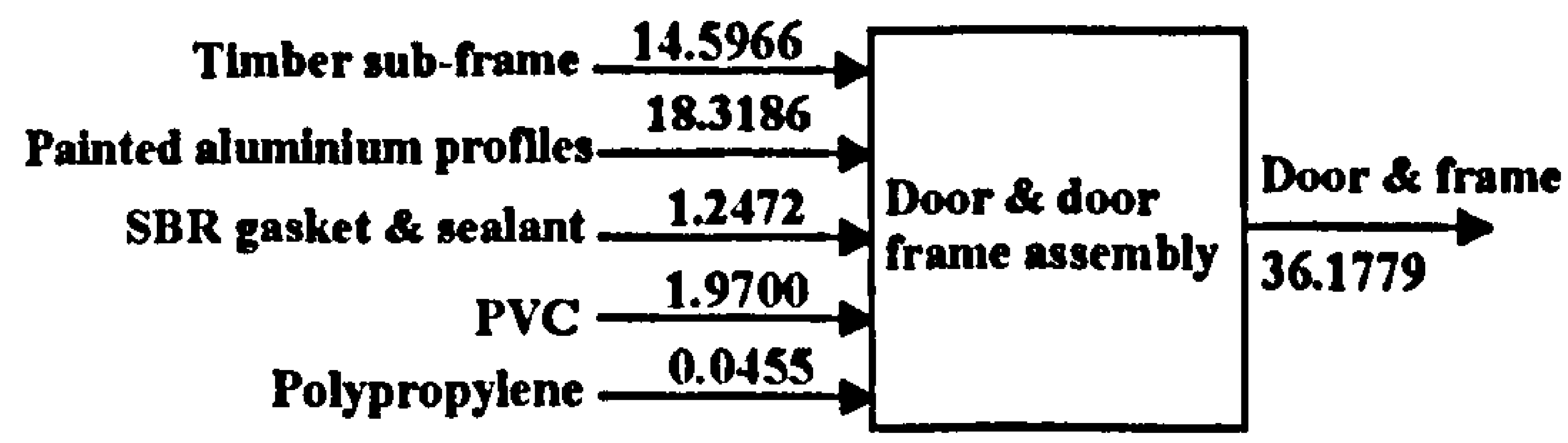
Water emissions	mg
COD	3,683
BOD	1,415
Salt	60
Acid	4,108
NO_3^-	1
Metals	1,452
Cl^-	116,435
F^-	37,084
Dissolved organics	2,217
Suspended solids	8,432,900
Detergent/oil	81
HC	2,674
Organo-chlorine	5
Phenol	1,248
Dissolved solids	934
Other N	5
Na^+	13,218
SO_4^{2-}	7,679
Phosphate/P_2O_5	1
Other organic	11
Al^{3+}	5,807

Solid waste	mg
Plastic containers	14,113
Paper	525
Plastics	60
Metals	9
Organics	16
Mineral waste	120,581,600
Slags/ash	4,637,200
Industrial waste	2,508,200
Regulated chemicals	5,567
Unregulated chemicals	27,832

Packaging & delivery: Bulk delivery, no packaging
Road transport: rigid vehicle, 5.5 tonne payload, returning empty, average return distance 32 km

Appendix 65 Metals and metal products

Production and road delivery of powder painted aluminium external kitchen door and frame (762 x 1981) mm -per door/frame



Schematic flow diagram for the production of powder painted aluminium door & frame (762mm x 1981mm) opening. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of powder painted aluminium external kitchen door and frame, (762mm x 1981mm) opening - per door/frame Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	876.48
Electricity - delivered	1,215.73
Oil fuels - production & delivery	187.35
Oil fuels - delivered	638.70
Oil fuels - feedstock	663.13
Other fuels - production & delivery	70.15
Other fuels - delivered	726.48
Other fuels - feedstock	288.62
Total energy	4,666.63

Primary fuels	MJ
Coal	497.30
Oil	832.45
Gas	724.48
Hydro	1,313.05
Nuclear	201.75
Lignite	0.04
Wood	145.81
Sulphur	6.95
Recovered	-7.7
Total fuels	3,714.12
Primary feedstocks	**MJ**
Coal	3.58
Oil	661.50
Gas	38.49
Wood	247.23
Total feedstocks	950.80
Total fuels & feedstocks	4,664.92

Raw materials	mg
Barytes	84,229
Bauxite	72,110,300
Brine	10,485,200
$CaSO_4$	172
Chalk	94,919
Clay	71
Fe-Mn	902
Fluorspar	1,599,200
Iron ore	276,835
Lead	634
Limestone	618,573
Magnesium	97,324
Met coal	113,399
Rutile	825,417
Sand	180,031
Water	1,633,400,000
Wood	44,746,500
Shale	489
NaCl	1,074,600
Nitrogen	12,891
Air	11,403,700
Sulphur	750,797
Chromium	23,637

Water emissions	mg
COD	6,724
BOD	2,465
Salt	85
Acid	2,769
NO_3^-	1
Metals	1,130
Cl^-	78,020
F^-	37,077
Dissolved organics	16,704
Suspended solids	7,158,600
Detergent/oil	103
HC	2,999
Organo-chlorine	5
Phenol	1,188
Dissolved solids	1,554
Other N	5
Na^+	9,382
SO_4^{2-}	2,474
Phosphate/P_2O_5	1
Other organic	11

Air emissions	mg
Dust	1,049,200
CO	9,680,300
CO_2	167,983,900
SO_x	1,399,200
NO_x	1,039,300
NH_3	4
CL_2	4
HCl	9,797
F	104,403
HF	472
HC	517,846
Organics	10,364
Lead	6
Metals	527
CH_4	940,911
Organo-chlorine	807

Solid waste	mg
Plastic containers	14,113
Paper	525
Plastics	94
Metals	9
Organics	34
Mineral waste	115,451,100
Slags/ash	2,491,800
Industrial waste	1,490,700
Regulated chemicals	5,685
Unregulated chemicals	20,132

Packaging & delivery: Bulk delivery, no packaging
Road transport: rigid vehicle, 5.5 tonne payload, returning empty, average return distance 32 km

Production and road delivery of 100 mm half round cast aluminium rainwater guttering -per metre

Deliver 6063 Al ingot 1.2000 → Melt & cast gutter → Al gutter 1.2000

Schematic flow diagram for the production of 100 mm half round cast aluminium rainwater guttering. All flows are in kg/metre

Gross inputs and outputs associated with the production and road delivery of 100 mm half round cast aluminum guttering- per metre Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	31.34
Electricity - delivered	68.53
Oil fuels - production & delivery	8.55
Oil fuels - delivered	25.71
Oil fuels - feedstock	34.54
Other fuels - production & delivery	2.37
Other fuels - delivered	20.91
Other fuels - feedstock	0.05
Total energy	192.00

Primary fuels	MJ
Coal	9.45
Oil	32.37
Gas	26.41
Hydro	85.59
Nuclear	3.62
Sulphur	0.34
Recovered	-0.37
Total fuels	157.41
Primary feedstocks	**MJ**
Coal	0.07
Oil	34.52
Total feedstocks	34.59
Total fuels & feedstocks	192.00

Raw materials	mg
Bauxite	4,740,000
Brine	596,021
$CaSO_4$	11
Fe-Mn	18
Fluorspar	86,097
Iron ore	5,394
Lead	4
Limestone	24,752
Magnesium	6,398
Met coal	2,219
Sand	11,716
Water	50,549,900
Shale	31
NaCl	23
Nitrogen	691
Air	550,366
Sulphur	36,235

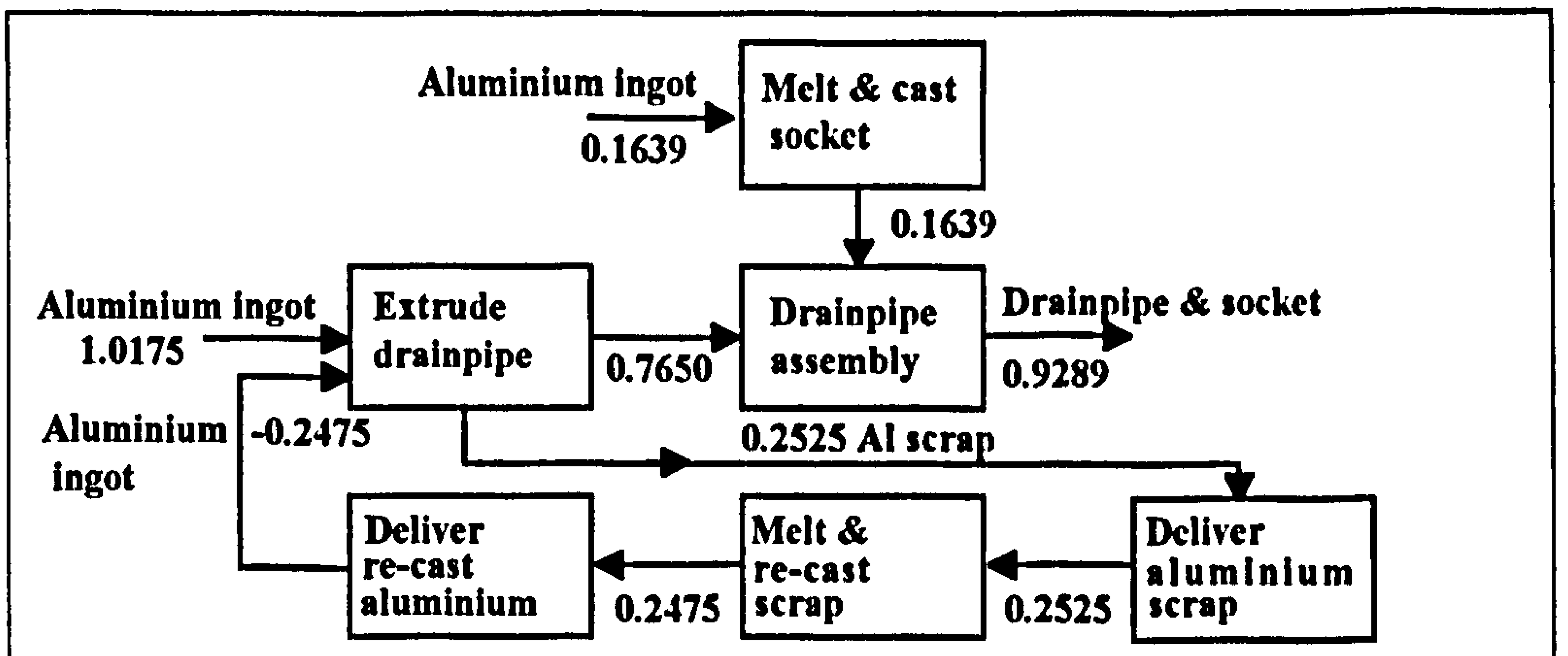
Water emissions	mg
COD	70
BOD	62
Salt	3
Acid	85
Metals	24
Cl^-	608
F^-	2,437
Suspended solids	458,849
HC	63
Phenol	62
Dissolved solids	11
Na^+	4
SO_4^{2-}	1

Air emissions	mg
Dust	104,191
CO	624,869
CO_2	5,543,200
SO_x	52,022
NO_x	32,266
HCl	183
F	6,863
HF	10
HC	16,500
Metals	26
CH_4	33,696

Solid waste	mg
Mineral waste	7,335,500
Slags/ash	113,912
Industrial waste	7,787

Packaging & delivery: Bulk delivery, no packaging
Road transport:rigid vehicle, 20000 kg payload, returning empty, average return distance 322 km

Production and road delivery of 68 mm (external diameter) aluminium drainpipe -per metre



Schematic flow diagram for the production of 68 mm diameter aluminium drainpipe
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of 68 mm diameter aluminum drainpipe-per metre Totals may not agree because of rounding error

Energy	MJ
Electricity - production & delivery	30.72
Electricity - delivered	55.66
Oil fuels - production & delivery	6.87
Oil fuels - delivered	21.70
Oil fuels - feedstock	26.67
Other fuels - production & delivery	1.60
Other fuels - delivered	14.12
Other fuels - feedstock	0.06
Total energy	157.39

Raw materials	mg
Bauxite	3,658,700
Brine	460,056
$CaSO_4$	9
Fe-Mn	20
Fluorspar	66,456
Iron ore	5,995
Lead	6
Limestone	19,771
Magnesium	4,938
Met coal	2,466
Sand	9,045
Water	39,653,500
Shale	24
NaCl	17
Nitrogen	534
Air	424,926
Sulphur	27,976

Air emissions	
Dust	52,436
CO	483,075
CO_2	4,852,700
SO_x	49,338
NO_x	26,504
HCl	255
F	5,297
HF	13
HC	12,484
Metals	22
CH_4	24,659

Primary fuels	MJ
Coal	13.10
Oil	27.92
Gas	18.42
Hydro	66.18
Nuclear	5.06
Sulphur	0.26
Recovered	-0.29
Total fuels	130.65
Primary feedstocks	**MJ**
Coal	0.08
Oil	26.64
Total feedstocks	26.72
Total fuels & feedstocks	157.37

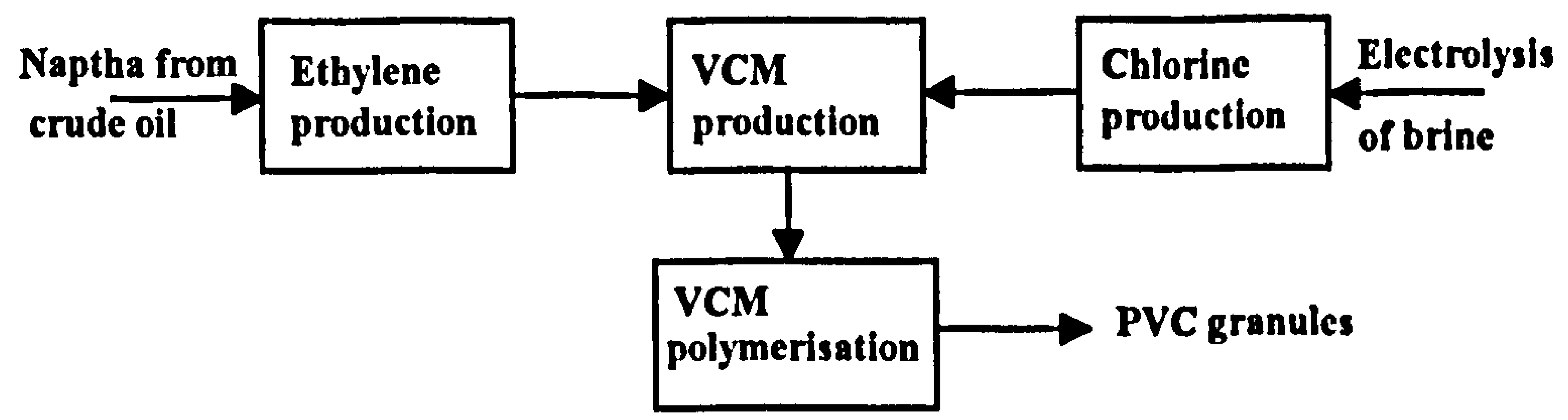
Water emissions	mg
COD	57
BOD	50
Salt	3
Acid	81
Metals	23
Cl^-	470
F^-	1,881
Suspended solids	354,525
HC	53
Phenol	51
Dissolved solids	8
Na^+	3
SO_4^{2-}	1

Solid waste	mg
Mineral waste	5,704,600
Slags/ash	100,340
Industrial waste	6,333

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 68 Plastics and plastic products

Production and road delivery of suspension PVC granules - per kg



Schematic flow diagram for the production of PVC granules

Gross inputs and outputs associated with the production and bulk road delivery of suspension PVC granules - per kg [1]

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	9.08
Electricity - delivered	3.84
Oil fuels - production & delivery	2.54
Oil fuels - delivered	1.94
Oil fuels - feedstock	16.12
Other fuels - production & delivery	3.20
Other fuels - delivered	14.03
Other fuels - feedstock	14.43
Total energy	65.17

Raw materials	mg
Bauxite	223
Brine	2
Fe-Mn	2
Iron ore	922
Lead	1
Limestone	15,195
Met coal	227
Sand	1,000
Water	20,015,500
NaCl	675,000
Air	35
Sulphur	2

Air emissions	mg
Dust	3,917
CO	2,637
CO_2	1,762,900
SO_x	13,092
NO_x	15,179
Cl_2	1
HCl	240
HC	19,057
Metals	3
CH_4	9
Organo-chlorine	510

Primary fuels	MJ
Coal	8.15
Oil	4.81
Gas	18.32
Hydro	0.15
Nuclear	3.19
Total fuels	34.62
Primary feedstocks	**MJ**
Coal	0.02
Oil	16.11
Gas	14.42
Total feedstocks	30.55
Total fuels & feedstocks	65.17

Water emissions	mg
COD	1,100
BOD	80
Acid	170
Metals	200
Cl^-	42,000
Dissolved organics	1,400
Suspended solids	2,071
Detergent/oil	50
Organo-chlorine	3
Dissolved solids	420
Other N	3
Na^+	4,800
SO_4^{2-}	1,500

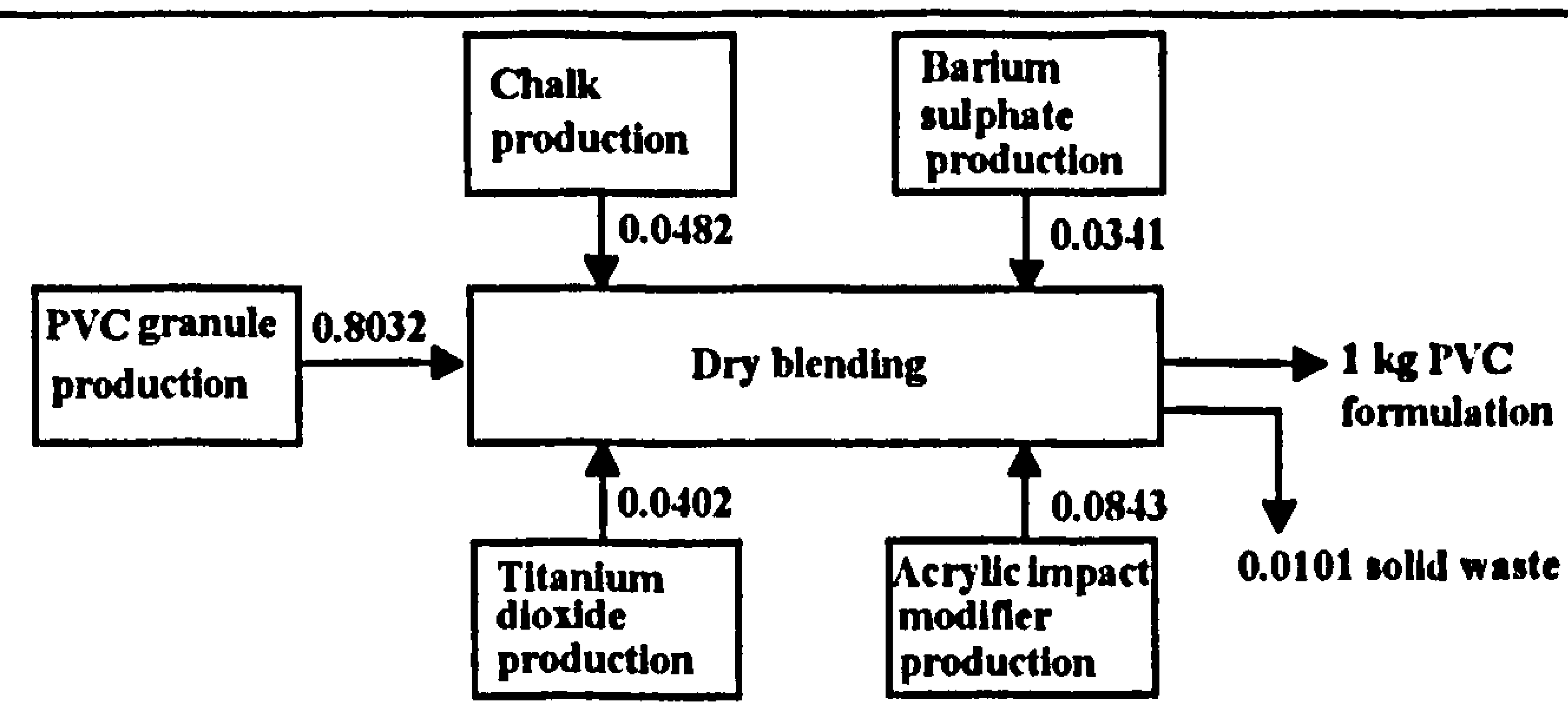
Solid waste	mg
Mineral waste	60,833
Slags/ash	12,045
Industrial waste	2,023
Regulated chemicals	3,500
Unregulated chemicals	11,000

1 PVC production data: I. Boustead, *Ecoprofiles of the European polymer industry*, APME Report No. 6, Polyvinylchloride, April 1994.

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 69 Plastics and plastic products

Production and road delivery of a PVC formulation used in the production of window/door frame profiles - per kg



Schematic flow diagram for the production of a PVC formulation used in the production of window/door frame profiles All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a PVC formulation used in the production of window/door frame profiles- per kg Totals may not agree because of rounding errors

Energy	**MJ**
Electricity - production & delivery	10.16
Electricity - delivered	4.30
Oil fuels - production & delivery	2.93
Oil fuels - delivered	4.14
Oil fuels - feedstock	16.61
Other fuels - production & delivery	2.87
Other fuels - delivered	13.31
Other fuels - feedstock	12.05
Total energy	66.38

Primary fuels	**MJ**
Coal	9.38
Oil	7.39
Gas	17.20
Hydro	0.17
Nuclear	3.57
Sulphur	0.04
Recovered	-0.05
Total fuels	37.70

Primary feedstocks	**MJ**
Coal	0.04
Oil	16.59
Gas	12.02
Total feedstocks	28.65
Total fuels & feedstocks	66.35

Raw materials	**mg**
Barytes	42,726
Bauxite	189
Brine	46,803
Chalk	48,182
Clay	35
Fe-Mn	7
Iron ore	2,511
Lead	4
Limestone	22,087
Met coal	911
Rutile	45,227
Sand	804
Water	23,995,500
Wood	750
NaCl	542,182
Nitrogen	3
Air	72,508
Sulphur	4,774

Water emissions	**mg**
COD	896
BOD	71
Salt	4
Acid	144
Metals	163
Cl^-	33,783
Dissolved organics	1,125
Suspended solids	15,693
Detergent/oil	40
Hydrocarbons	7
Organo-chlorine	2
Phenol	7
Dissolved solids	347
Other N	2
Na^+	3,856
SO_4^{2-}	1,205

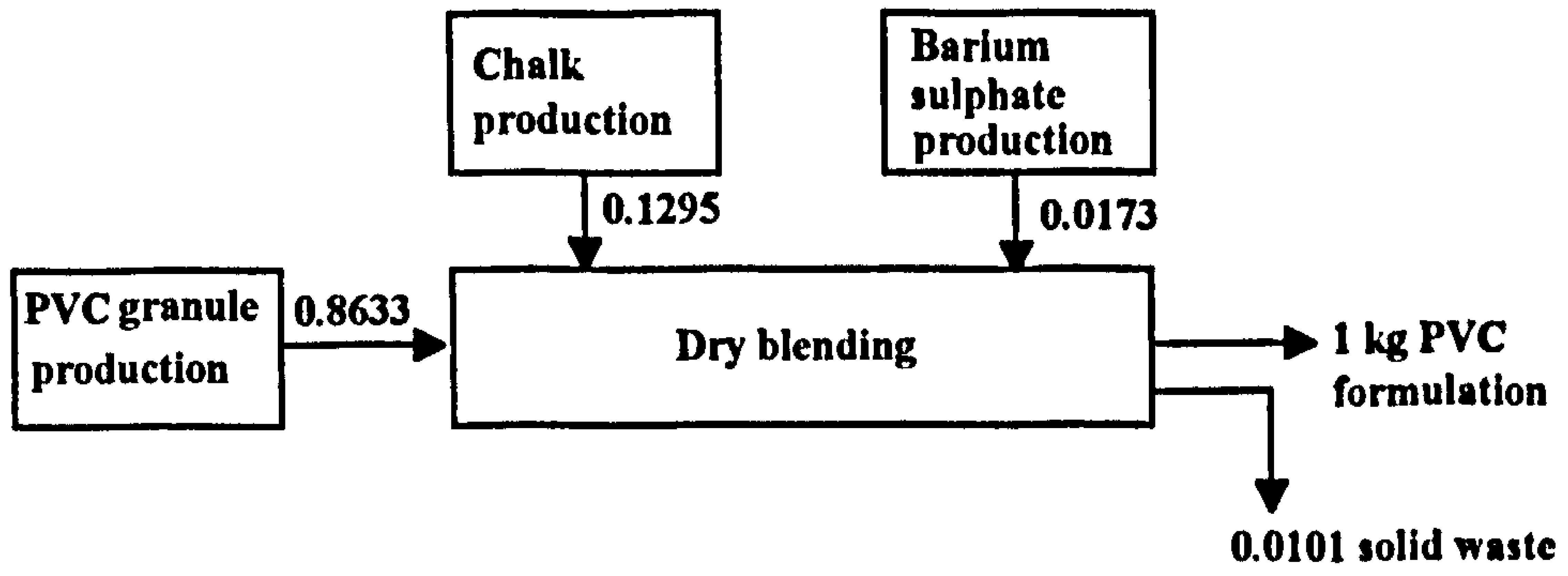
Air emissions	**mg**
Dust	4,724
CO	2,717
CO_2	2,019,300
SO_x	17,138
NO_x	16,097
NH_3	2
Cl_2	1
HCl	248
HF	3
HC	17,090
Metals	5
CH_4	4,189
Organo-chlorine	410

Solid waste	**mg**
Paper	265
Mineral waste	125,302
Slags/ash	20,332
Industrial waste	12,511
Regulated chemicals	2,811
Unregulated chemicals	9,124

Packaging & delivery: Bulk delivery, no packaging
Road transport: articulated tanker, 22.5 tonne payload, returning empty, average return distance 869 km

Appendix 70 Plastics and plastic products

Production and road delivery of a PVC formulation used in the production of surface rainwater drainage systems - per kg



Schematic flow diagram for the production of a PVC formulation used in the production of surface rainwater drainage systems All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a PVC formulation used in the production of surface rainwater drainage systems- per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	9.70
Electricity - delivered	4.11
Oil fuels - production & delivery	2.29
Oil fuels - delivered	2.34
Oil fuels - feedstock	13.93
Other fuels - production & delivery	2.79
Other fuels - delivered	12.29
Other fuels - feedstock	12.48
Total energy	59.92

Raw materials	mg
Barytes	21,613
Bauxite	202
Brine	6,916
Chalk	129,500
Clay	18
Fe-Mn	7
Iron ore	2,384
Lead	4
Limestone	18,363
Met coal	849
Sand	864
Water	18,095,900
Wood	379
NaCl	582,748
Nitrogen	1
Air	36,734
Sulphur	2,418

Air emissions	mg
Dust	4,268
CO	2,756
CO_2	1,747,200
SO_x	13,915
NO_x	14,327
Cl_2	1
HCl	242
HF	2
HC	16,760
Metals	3
CH_4	622
Organo-chlorine	440

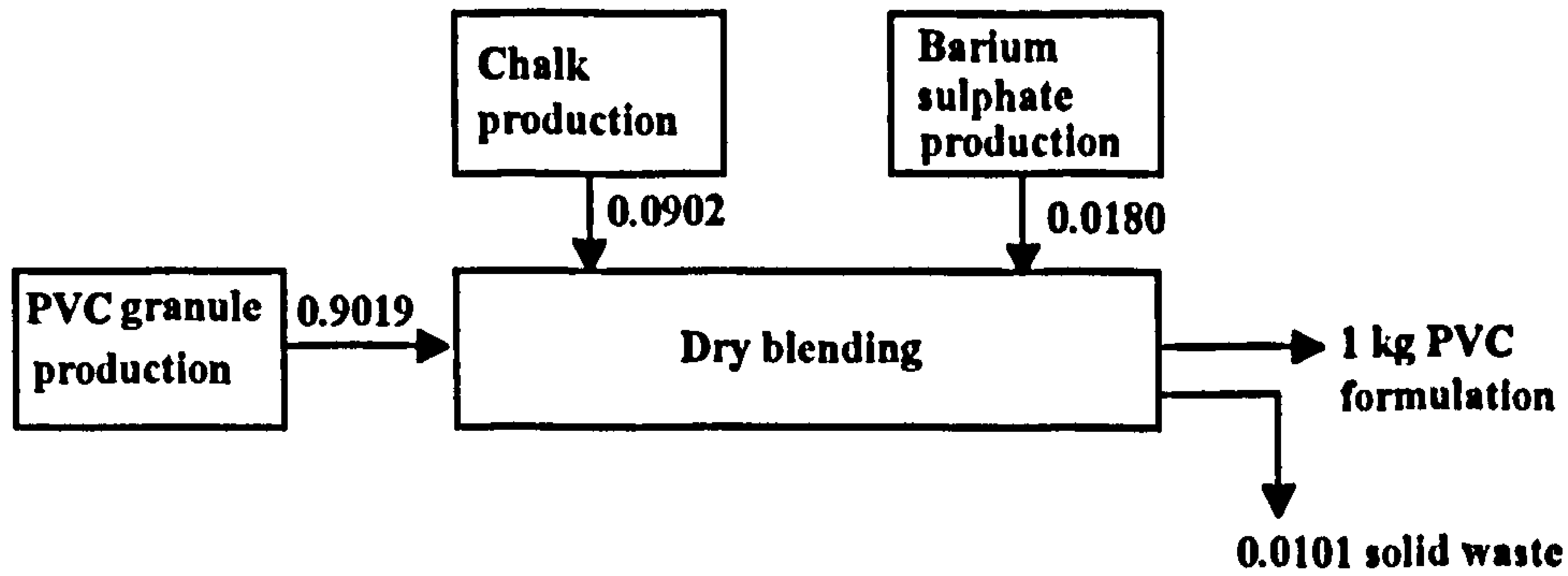
Primary fuels	MJ
Coal	8.83
Oil	5.12
Gas	15.99
Hydro	0.16
Nuclear	3.40
Sulphur	0.02
Recovered	-0.02
Total fuels	33.50
Primary feedstocks	**MJ**
Coal	0.04
Oil	13.91
Gas	12.45
Total feedstocks	26.40
Total fuels & feedstocks	59.89

Water emissions	mg
COD	953
BOD	70
Salt	2
Acid	151
Metals	174
Cl^-	36,267
Dissolved organics	1,209
Suspended solids	16,753
Detergent/oil	43
Hydrocarbons	1
Organo-chlorine	3
Phenol	1
Dissolved solids	367
Other N	3
Na^+	4,144
SO_4^{2-}	1,295

Solid waste	mg
Paper	134
Mineral waste	71,725
Slags/ash	16,578
Industrial waste	11,954
Regulated chemicals	3,022
Unregulated chemicals	9,643

Packaging & delivery: Bulk delivery, no packaging
Road transport: articulated tanker, 22.5 tonne payload, returning empty, average return distance 869 km

Production and road delivery of a PVC formulation used in the production of sewage pipes - per kg



Schematic flow diagram for the production of a PVC formulation used in the production of sewage pipes All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a PVC formulation used in the production of sewage pipes- per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	10.07
Electricity - delivered	4.26
Oil fuels - production & delivery	2.39
Oil fuels - delivered	2.40
Oil fuels - feedstock	14.55
Other fuels - production & delivery	2.92
Other fuels - delivered	12.84
Other fuels - feedstock	13.04
Total energy	62.45

Primary fuels	MJ
Coal	9.16
Oil	5.30
Gas	16.70
Hydro	0.17
Nuclear	3.53
Sulphur	0.02
Recovered	-0.03
Total fuels	34.85

Primary feedstocks	MJ
Coal	0.04
Oil	14.53
Gas	13.01
Total feedstocks	27.57
Total fuels & feedstocks	62.42

Raw materials	mg
Barytes	22,526
Bauxite	210
Brine	7,208
Chalk	90,200
Clay	19
Fe-Mn	7
Iron ore	2,402
Lead	4
Limestone	19,140
Met coal	851
Sand	603
Water	18,894,600
Wood	395
NaCl	608,783
Nitrogen	2
Air	38,284
Sulphur	2,521

Water emissions	mg
COD	996
BOD	73
Salt	2
Acid	158
Metals	182
Cl^-	37,887
Dissolved organics	1,263
Suspended solids	13,223
Detergent/oil	45
Hydrocarbons	1
Organo-chlorine	3
Phenol	1
Dissolved solids	384
Other N	3
Na^+	4,329
SO_4^{2-}	1,353

Air emissions	mg
Dust	4,428
CO	2,854
CO_2	1,816,500
SO_x	14,438
NO_x	14,913
Cl_2	1
HCl	252
HF	2
HC	17,495
Metals	3
CH_4	631
Organo-chlorine	460

Solid waste	mg
Paper	140
Mineral waste	74,375
Slags/ash	17,180
Industrial waste	12,031
Regulated chemicals	3,157
Unregulated chemicals	10,073

Packaging & delivery: Bulk delivery, no packaging
Road transport: articulated tanker, 22.5 tonne payload, returning empty, average return distance 869 km

Appendix 72 Plastics and plastic products

Production and road delivery of extruded PVC window/door frame profiles - per kg

PVC granule formulation $\xrightarrow{1.0000}$ PVC extrusion $\longrightarrow$ 1 kg extruded profile

Schematic flow diagram for the production of extruded PVC window/door profiles
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of extruded PVC window/door profiles - per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	22.64
Electricity - delivered	9.58
Oil fuels - production & delivery	2.99
Oil fuels - delivered	4.53
Oil fuels - feedstock	16.62
Other fuels - production & delivery	2.87
Other fuels - delivered	13.33
Other fuels - feedstock	12.08
Total energy	84.64

Raw materials	mg
Barytes	42,726
Bauxite	205
Brine	46,808
Chalk	48,182
Clay	35
Fe-Mn	16
Iron ore	5,199
Lead	7
Limestone	23,072
Met coal	2,017
Rutile	45,227
Sand	809
Water	25,078,100
Wood	750
NaCl	542,182
Nitrogen	3
Air	72,673
Sulphur	4,785

Air emissions	mg
Dust	9,950
CO	3,726
CO_2	3,067,500
SO_x	30,796
NO_x	20,590
NH_3	2
Cl_2	1
HCl	466
HF	14
HC	17,915
Metals	6
CH_4	7,391
Organo-chlorine	410

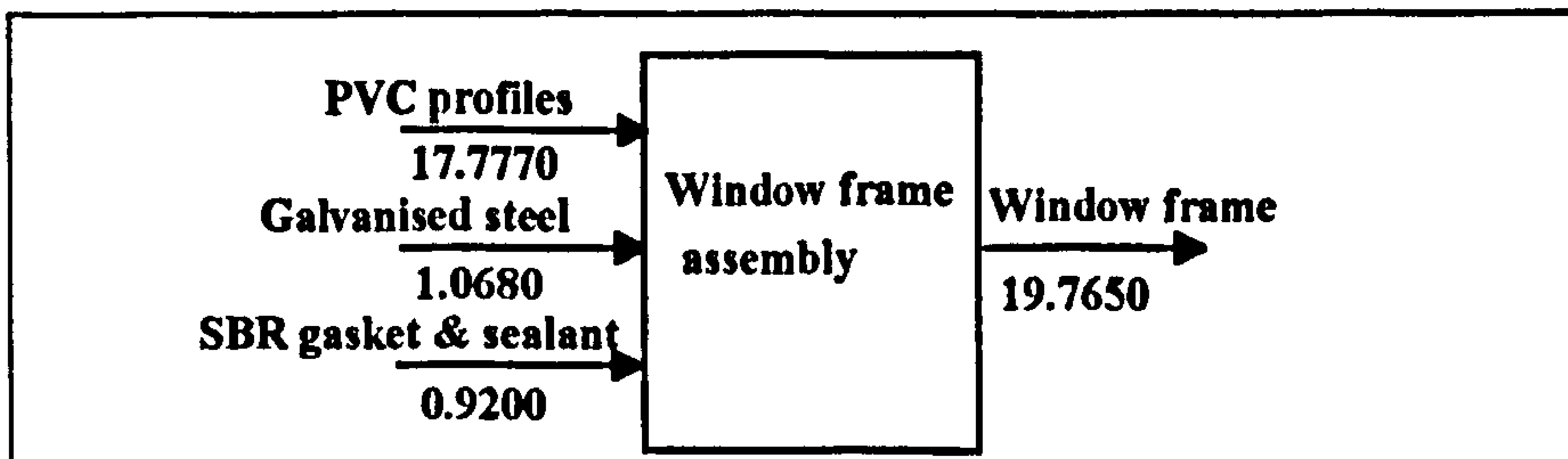
Primary fuels	MJ
Coal	20.47
Oil	9.56
Gas	17.62
Hydro	0.38
Nuclear	7.89
Sulphur	0.04
Recovered	-0.05
Total fuels	55.92
Primary feedstocks	**MJ**
Coal	0.07
Oil	16.59
Gas	12.02
Total feedstocks	28.69
Total fuels & feedstocks	84.61

Water emissions	mg
COD	899
BOD	73
Salt	4
Acid	173
Metals	172
Cl^-	33,783
Dissolved organics	1,125
Suspended solids	16,260
Detergent/oil	40
Hydrocarbons	11
Organo-chlorine	2
Phenol	9
Dissolved solids	347
Other N	2
Na^+	3,856
SO_4^{2-}	1,205

Solid waste	mg
Paper	265
Plastics	1
Mineral waste	205,484
Slags/ash	44,018
Industrial waste	12,753
Regulated chemicals	2,811
Unregulated chemicals	9,124

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5 tonne payload, returning empty, average return distance 322 km

Production and road delivery of PVC casement window frames (1200 x 1200 mm) - per frame



Schematic flow diagram for the production of PVC casement window frames (1200mm x 1200mm) opening. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of PVC casement window frames (1200mm x 1200mm) opening - per frame Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	475.57
Electricity - delivered	201.34
Oil fuels - production & delivery	62.21
Oil fuels - delivered	103.04
Oil fuels - feedstock	337.56
Other fuels - production & delivery	52.88
Other fuels - delivered	252.21
Other fuels - feedstock	228.53
Total energy	1,713.34

Raw materials	mg
Barytes	744,353
Bauxite	11,740
Brine	1,366,200
$CaSO_4$	5
Chalk	839,403
Clay	611
Fe-Mn	4,908
Fluorspar	158
Iron ore	1,504,900
Lead	142
Limestone	902,357
Met coal	616,904
Rutile	787,927
Sand	14,121
Water	531,978,300
Wood	13,060
Zinc	59,456
Shale	15
NaCl	9,445,600
Nitrogen	60
Air	1,468,900
Sulphur	96,708

Air emissions	mg
Dust	215,018
CO	73,079
CO_2	63,885,900
SO_x	766,508
NO_x	420,146
NH_3	30
Cl_2	14
HCl	9,544
F	41
HF	308
HC	335,126
Metals	143
CH_4	183,983
Organo-chlorine	7,138

Primary fuels	MJ
Coal	429.06
Oil	208.55
Gas	335.38
Hydro	8.03
Nuclear	165.82
Lignite	0.04
Sulphur	0.90
Recovered	-0.99
Total fuels	1,146.79
Primary feedstocks	**MJ**
Coal	19.46
Oil	337.03
Gas	209.41
Wood	0.12
Total feedstocks	566.01
Total fuels & feedstocks	1,712.79

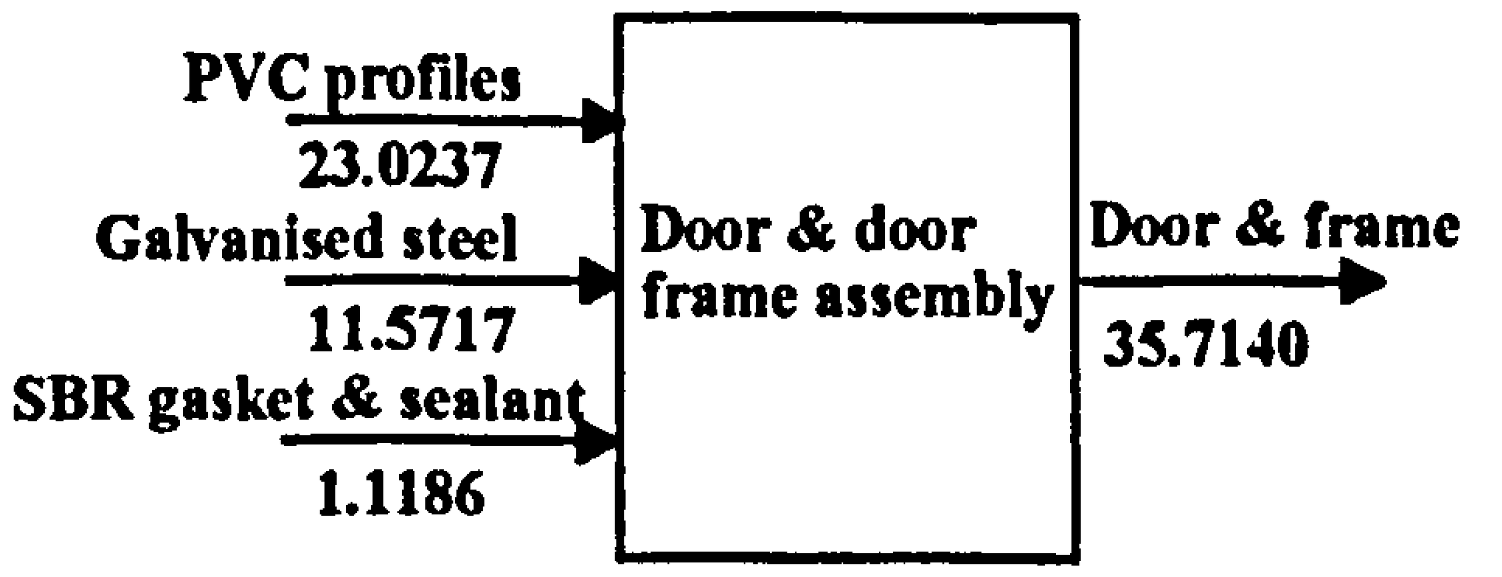
Water emissions	mg
COD	15,761
BOD	1,363
Salt	72
Acid	3,445
Metals	3,122
Cl^-	589,095
F	4
Dissolved organics	19,591
Suspended solids	466,790
Detergent/oil	700
Hydrocarbons	286
Organo-chlorine	42
Phenol	237
Dissolved solids	6,039
Other N	43
Na^+	67,169
SO_4^{2-}	20,990

Solid waste	mg
Plastic containers	3
Paper	4,624
Plastics	24
Metals	3
Organics	8
Mineral waste	6,192,200
Slags/ash	1,027,800
Industrial waste	232,021
Regulated chemicals	48,977
Unregulated chemicals	158,958

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5 tonne payload, returning empty, average return distance 32 km

Appendix 74 Plastics and plastic products

Production and road delivery of PVC external kitchen door and frame (762 mm x 1981 mm) -per door/frame



Schematic flow diagram for the production of PVC door & frame (762mm x 1981mm) opening. All flows are in kg

Gross inputs and outputs associated with the production and road delivery of PVC external kitchen door and frame (762mm x 1981mm) opening - per door/frame Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	681.55
Electricity - delivered	289.43
Oil fuels - production & delivery	84.23
Oil fuels - delivered	161.78
Oil fuels - feedstock	434.11
Other fuels - production & delivery	80.46
Other fuels - delivered	381.23
Other fuels - feedstock	468.25
Total energy	2,581.05

Raw materials	mg
Barytes	964,042
Bauxite	92,555
Brine	1,849,000
$CaSO_4$	8
Chalk	1,087,100
Clay	792
Fe-Mn	50,183
Fluorspar	1,609
Iron ore	15,341,500
Lead	221
Limestone	5,905,100
Met coal	6,307,900
Rutile	1,020,500
Sand	18,321
Water	871,488,200
Wood	16,915
Zinc	644,197
Shale	22
NaCl	12,233,400
Nitrogen	139
Air	3,178,200
Sulphur	209,249

Air emissions	mg
Dust	362,464
CO	119,338
CO_2	97,607,300
SO_x	2,142,900
NO_x	681,699
NH_3	39
Cl_2	18
HCl	13,552
F	423
HF	458
HC	482,487
Metals	215
CH_4	380,484
Organo-chlorine	9,243

Primary fuels	MJ
Coal	616.62
Oil	311.57
Gas	498.68
Hydro	12.91
Nuclear	238.33
Lignite	0.06
Sulphur	1.94
Recovered	-2.15
Total fuels	1,677.96

Primary feedstocks	MJ
Coal	197.72
Oil	433.26
Gas	271.21
Wood	0.15
Total feedstocks	902.35
Total fuels & feedstocks	2,580.31

Water emissions	mg
COD	20,456
BOD	1,801
Salt	94
Acid	6,965
Metals	4,661
Cl^-	763,038
F^-	46
Dissolved organics	25,373
Suspended solids	2,329,800
Detergent/oil	906
Hydrocarbons	415
Organo-chlorine	54
Phenol	342
Dissolved solids	7,823
Other N	56
Na^+	86,994
SO_4^{2-}	27,186

Solid waste	mg
Plastic containers	4
Paper	5,989
Plastics	35
Metals	4
Organics	12
Mineral waste	28,451,200
Slags/ash	2,474,600
Industrial waste	304,716
Regulated chemicals	63,432
Unregulated chemicals	205,872

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5 tonne payload, returning empty, average return distance 32 km

Appendix 75 Plastics and plastic products

Production and road delivery of a 68 mm (external diameter) PVC drainpipe - per metre

PVC granule formulation $\xrightarrow{0.6125}$ PVC extrusion $\rightarrow$ 0.6125 kg (1 metre) PVC drainpipe

Schematic flow diagram for the production of a 68 mm diameter PVC drainpipe
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a 68 mm diameter PVC drainpipe - per metre Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	13.59
Electricity - delivered	5.75
Oil fuels - production & delivery	1.44
Oil fuels - delivered	1.67
Oil fuels - feedstock	8.54
Other fuels - production & delivery	1.71
Other fuels - delivered	7.54
Other fuels - feedstock	7.66
Total energy	47.88

Raw materials	mg
Barytes	13,238
Bauxite	133
Brine	4,239
Chalk	79,319
Clay	11
Fe-Mn	10
Iron ore	3,107
Lead	4
Limestone	11,851
Met coal	1,198
Sand	532
Water	11,746,900
Wood	232
NaCl	356,933
Air	22,602
Sulphur	1,488

Air emissions	mg
Dust	5,815
CO	2,306
CO_2	1,712,100
SO_x	16,888
NO_x	11,527
Cl_2	1
HCl	282
HF	8
HC	10,771
Metals	3
CH_4	2,342
Organo-chlorine	270

Primary fuels	MJ
Coal	12.20
Oil	4.47
Gas	10.05
Hydro	0.23
Nuclear	4.73
Sulphur	0.01
Recovered	-0.02
Total fuels	31.68
Primary feedstocks	**MJ**
Coal	0.04
Oil	8.52
Gas	7.63
Total feedstocks	16.19
Total fuels & feedstocks	47.86

Water emissions	mg
COD	586
BOD	44
Salt	1
Acid	110
Metals	112
Cl^-	22,213
Dissolved organics	740
Suspended solids	10,609
Detergent/oil	26
Hydrocarbons	3
Organo-chlorine	2
Phenol	2
Dissolved solids	225
Other N	2
Na^+	2,538
SO_4^{2-}	793

Solid waste	mg
Paper	82
Mineral waste	93,043
Slags/ash	24,662
Industrial waste	7,470
Regulated chemicals	1,851
Unregulated chemicals	5,906

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5t payload, returning empty, average return distance 322 km

Appendix 76 Plastics and plastic products

Production and road delivery of a 100 mm half round PVC rainwater gutter - per metre

PVC granule formulation $\xrightarrow{0.5500}$ **PVC extrusion** $\rightarrow$ **0.5500 kg (1 metre) PVC gutter**

Schematic flow diagram for the production of a 100 mm half round PVC gutter
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a 100 mm half round PVC rainwater gutter - per metre Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	12.20
Electricity - delivered	5.16
Oil fuels - production & delivery	1.29
Oil fuels - delivered	1.50
Oil fuels - feedstock	7.67
Other fuels - production & delivery	1.54
Other fuels - delivered	6.77
Other fuels - feedstock	6.88
Total energy	43.00

Raw materials	mg
Barytes	11,887
Bauxite	120
Brine	3,806
Chalk	71,225
Clay	10
Fe-Mn	9
Iron ore	2,790
Lead	4
Limestone	10,642
Met coal	1,075
Sand	478
Water	10,548,200
Wood	209
NaCl	320,511
Air	20,296
Sulphur	1,336

Air emissions	mg
Dust	5,222
CO	2,071
CO_2	1,537,400
SO_x	15,165
NO_x	10,351
HCl	253
HF	7
HC	9,672
Metals	2
CH_4	2,103
Organo-chlorine	242

Primary fuels	MJ
Coal	10.95
Oil	4.01
Gas	9.03
Hydro	0.20
Nuclear	4.25
Sulphur	0.01
Recovered	-0.01
Total fuels	28.44
Primary feedstocks	**MJ**
Coal	0.04
Oil	7.65
Gas	6.85
Total feedstocks	14.54
Total fuels & feedstocks	42.98

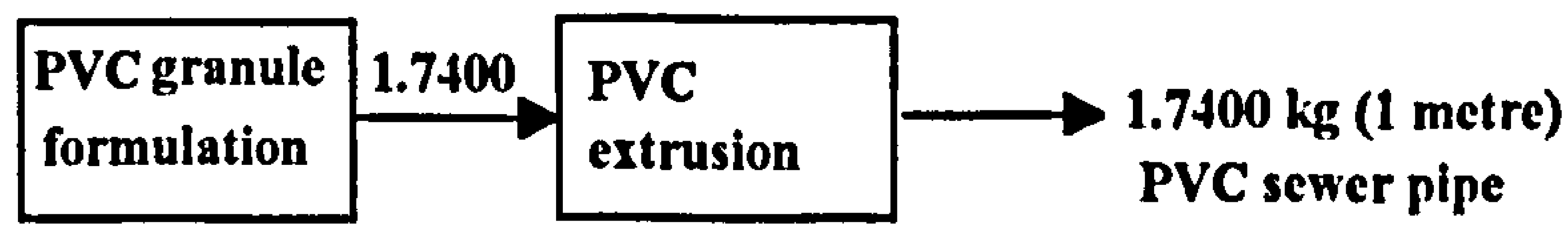
Water emissions	mg
COD	526
BOD	40
Salt	1
Acid	99
Metals	101
Cl^-	19,947
Dissolved organics	665
Suspended solids	9,526
Detergent/oil	24
Hydrocarbons	3
Organo-chlorine	1
Phenol	2
Dissolved solids	202
Other N	1
Na^+	2,279
SO_4^{2-}	712

Solid waste	mg
Paper	74
Mineral waste	83,549
Slags/ash	22,145
Industrial waste	6,708
Regulated chemicals	1,662
Unregulated chemicals	5,304

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5t payload, returning empty, average return distance 322 km

Appendix 77 Plastics and plastic products

Production and road delivery of a 110 mm (external diameter) PVC sewer pipe - per metre



Schematic flow diagram for the production of a 110 mm diameter PVC sewer pipe
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a 110 mm (external diameter) PVC sewer pipe - per metre Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	39.23
Electricity - delivered	16.60
Oil fuels - production & delivery	4.25
Oil fuels - delivered	4.85
Oil fuels - feedstock	25.33
Other fuels - production & delivery	5.08
Other fuels - delivered	22.36
Other fuels - feedstock	22.72
Total energy	140.43

Raw materials	mg
Barytes	39,196
Bauxite	393
Brine	12,550
Chalk	156,948
Clay	32
Fe-Mn	27
Iron ore	8,857
Lead	13
Limestone	35,019
Met coal	3,404
Sand	1,578
Water	34,760,400
Wood	688
Shale	1
NaCl	1,059,300
Nitrogen	3
Air	66,902
Sulphur	4,405

Air emissions	mg
Dust	16,799
CO	6,721
CO_2	4,984,600
SO_x	48,886
NO_x	33,767
Cl_2	2
HCl	817
HF	22
HC	31,877
Metals	8
CH_4	6,669
Organo-chlorine	800

Primary fuels	MJ
Coal	35.23
Oil	13.01
Gas	29.79
Hydro	0.65
Nuclear	13.66
Sulphur	0.04
Recovered	-0.05
Total fuels	92.34
Primary feedstocks	**MJ**
Coal	0.12
Oil	25.28
Gas	22.63
Total feedstocks	48.04
Total fuels & feedstocks	140.38

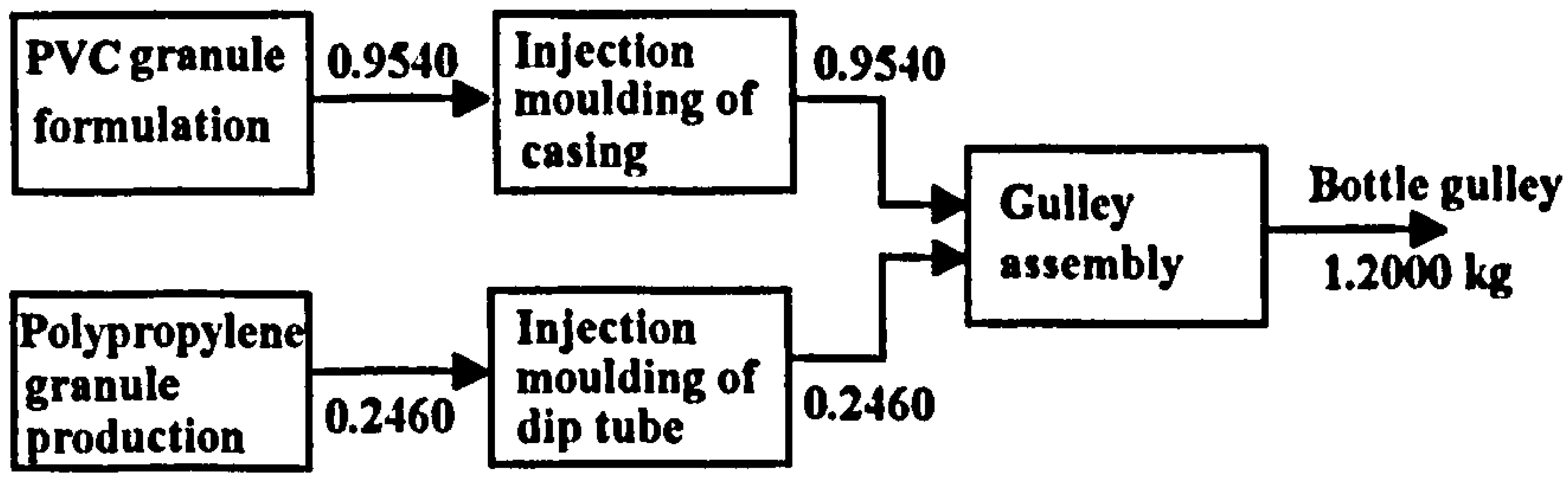
Water emissions	mg
COD	1,738
BOD	131
Salt	4
Acid	325
Metals	333
Cl^-	65,923
Dissolved organics	2,197
Suspended solids	23,994
Detergent/oil	78
Hydrocarbons	9
Organo-chlorine	5
Phenol	5
Dissolved solids	668
Other N	5
Na^+	7,533
SO_4^{2-}	2,354

Solid waste	mg
Paper	244
Plastics	2
Mineral waste	268,931
Slags/ash	71,107
Industrial waste	21,354
Regulated chemicals	5,493
Unregulated chemicals	17,527

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5t payload, returning empty, average return distance 322 km

Appendix 78 Plastics and plastic products

Production and road delivery of a PVC bottle gulley - per gulley



Schematic flow diagram for the production of a PVC bottle gulley
All flows are in kg

Gross inputs and outputs associated with the production and road delivery of a PVC bottle gulley - per gulley

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	25.76
Electricity - delivered	10.90
Oil fuels - production & delivery	3.94
Oil fuels - delivered	4.75
Oil fuels - feedstock	23.22
Other fuels - production & delivery	3.30
Other fuels - delivered	14.39
Other fuels - feedstock	14.88
Total energy	101.13

Raw materials	mg
Barytes	21,490
Bauxite	316
Brine	6,882
Chalk	86,051
Clay	25
Fe-Mn	16
Iron ore	5,354
Lead	7
Limestone	19,409
Met coal	2,041
Sand	867
Water	20,082,700
Wood	377
NaCl	582,009
Nitrogen	1
Air	36,717
Sulphur	2,417

Air emissions	mg
Dust	10,984
CO	4,085
CO_2	3,434,000
SO_x	32,842
NO_x	22,051
Cl_2	1
HCl	511
HF	15
HC	20,869
Metals	6
CH_4	4,440
Organo-chlorine	439

Primary fuels	MJ
Coal	23.14
Oil	10.81
Gas	19.65
Hydro	0.43
Nuclear	8.98
Sulphur	0.02
Recovered	-0.02
Total fuels	63.01
Primary feedstocks	**MJ**
Coal	0.07
Oil	23.19
Gas	14.82
Total feedstocks	38.09
Total fuels & feedstocks	101.10

Water emissions	mg
COD	1,052
BOD	87
Salt	2
Acid	207
NO_3^-	5
Metals	258
NH_4^+	2
Cl^-	36,341
Dissolved organics	1,212
Suspended solids	13,314
Detergent/oil	53
Hydrocarbons	80
Organo-chlorine	3
Phenol	3
Dissolved solids	415
Other N	5
Na^+	4,130
SO_4^{2-}	1,291
Phosphate/P_2O_5	5
Other organic	62

Solid waste	mg
Paper	134
Plastics	1
Mineral waste	170,260
Slags/ash	46,024
Industrial waste	12,748
Regulated chemicals	3,019
Unregulated chemicals	11,578

Packaging & delivery: Bulk delivery, no packaging
Road transport: 7.5t rigid vehicle, 5.5t payload, returning empty, average return distance 322 km

Appendix 79 Plastics and plastic products

Production and road delivery of polyethylene granules (all grades) - per kg

Naptha from crude oil → Ethylene production → Ethylene polymerisation → Polyethylene granules

Schematic flow diagram for the production of polyethylene granules

Gross inputs and outputs associated with the production and bulk road delivery of polyethylene granules (all grades) - per kg[1] Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	5.55
Electricity - delivered	2.35
Oil fuels - production & delivery	4.40
Oil fuels - delivered	7.59
Oil fuels - feedstock	23.58
Other fuels - production & delivery	4.31
Other fuels - delivered	14.14
Other fuels - feedstock	24.17
Total energy	86.08

Raw materials	mg
Bauxite	303
Brine	2
Clay	20
Fe-Mn	3
Iron ore	753
Lead	1
Limestone	351
Met coal	227
Sand	2
Water	1,815,400
NaCl	7,000
Air	74
Sulphur	5

Air emissions	mg
Dust	2,017
CO	937
CO_2	2,240,900
SO_x	7,093
NO_x	11,179
HCl	60
HF	1
HC	21,057
CHO	5
Organics	5
Metals	1
CH_4	9
Hydrogen	1

Primary fuels	MJ
Coal	5.09
Oil	11.10
Gas	20.06
Hydro	0.09
Nuclear	1.99
Total fuels	38.33
Primary feedstocks	**MJ**
Coal	0.02
Oil	23.57
Gas	24.16
Total feedstocks	47.75
Total fuels & feedstocks	86.08

Water emissions	mg
COD	1,000
BOD	150
Acid	70
NO_3^-	5
Metals	300
NH_4^+	5
Cl^-	120
Dissolved organics	20
Suspended solids	471
Detergent/oil	100
Hydrocarbons	100
Phenol	1
Dissolved solids	400
Other N	10
Sulphate	10
Phosphate/P_2O_5	5

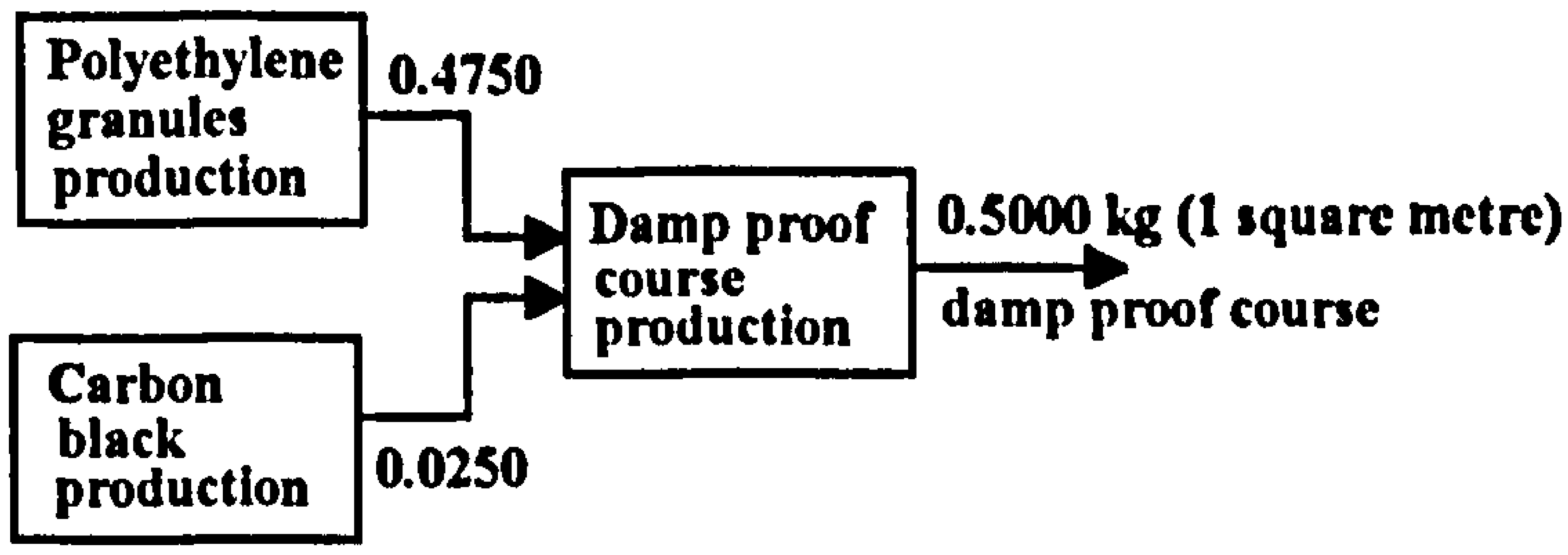
Solid waste	mg
Mineral waste	22,835
Slags/ash	7,045
Industrial waste	3,124
Regulated chemicals	70
Unregulated chemicals	2,000

1 Polyethylene production data: I. Boustead, *Ecoprofiles of the European polymer industry*, APME Report No. 3, Polyethylene and polypropylene, May 1993.

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 80 Plastics and plastic products

Production and road delivery of polyethylene damp proof course - per m²



Schematic flow diagram for the production of polyethylene damp proof course
All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of polyethylene damp proof course - per m² Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	6.88
Electricity - delivered	2.91
Oil fuels - production & delivery	2.50
Oil fuels - delivered	3.81
Oil fuels - feedstock	13.90
Other fuels - production & delivery	2.09
Other fuels - delivered	6.86
Other fuels - feedstock	11.72
Total energy	50.66

Raw materials	mg
Bauxite	154
Brine	3
Clay	10
Fe-Mn	6
Iron ore	1,630
Lead	3
Limestone	629
Met coal	631
Sand	3
Water	1,342,800
NaCl	3,392
Air	115
Sulphur	8

Air emissions	mg
Dust	2,758
CO	910
CO_2	1,456,300
SO_x	7,989
NO_x	7,168
HCl	102
HF	4
HC	10,638
CHO	2
Organics	2
Metals	1
CH_4	1,088

Primary fuels	MJ
Coal	6.20
Oil	6.31
Gas	9.98
Hydro	0.12
Nuclear	2.42
Total fuels	25.03
Primary feedstocks	**MJ**
Coal	0.02
Oil	13.88
Gas	11.71
Total feedstocks	25.61
Total fuels & feedstocks	50.64

Water emissions	mg
COD	488
BOD	76
Acid	44
NO_3^-	2
Metals	148
NH_4^+	2
Cl^-	58
Dissolved organics	10
Suspended solids	466
Detergent/oil	48
Hydrocarbons	52
Phenol	4
Dissolved solids	194
Other N	5
Sulphate	5
Phosphate/P_2O_5	2

Solid waste	mg
Mineral waste	38,554
Slags/ash	11,403
Industrial waste	1,886
Regulated chemicals	34
Unregulated chemicals	969

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 10 tonne payload, returning empty, average return distance 644 km

Appendix 81 Plastics and plastic products

Production and road delivery of polyethylene damp proof membrane (1200 gauge) - per kg

Polyethylene granule production	1.0000 →	Damp proof membrane production	1.0000 kg (4.26 square metre) →

Schematic flow diagram for the production of polyethylene damp proof membrane (1200 gauge). All flows are in kg

Gross inputs and outputs associated with the production and bulk road delivery of polyethylene damp proof membrane (1200 gauge) - per kg Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	14.10
Electricity - delivered	5.96
Oil fuels - production & delivery	4.54
Oil fuels - delivered	8.05
Oil fuels - feedstock	24.06
Other fuels - production & delivery	4.39
Other fuels - delivered	14.43
Other fuels - feedstock	24.66
Total energy	100.19

Primary fuels	MJ
Coal	12.68
Oil	12.84
Gas	20.74
Hydro	0.24
Nuclear	4.95
Total fuels	51.45
Primary feedstocks	**MJ**
Coal	0.04
Oil	24.04
Gas	24.64
Total feedstocks	48.72
Total fuels & feedstocks	100.17

Raw materials	mg
Bauxite	318
Brine	5
Clay	20
Fe-Mn	8
Iron ore	2,299
Lead	3
Limestone	923
Met coal	862
Sand	5
Water	2,580,700
NaCl	7,140
Air	170
Sulphur	11

Water emissions	mg
COD	1,022
BOD	155
Acid	91
NO_3^-	5
Metals	312
NH_4^+	5
Cl^-	122
Dissolved organics	20
Suspended solids	827
Detergent/oil	102
Hydrocarbons	105
Phenol	3
Dissolved solids	408
Other N	10
Sulphate	10
Phosphate/P_2O_5	5

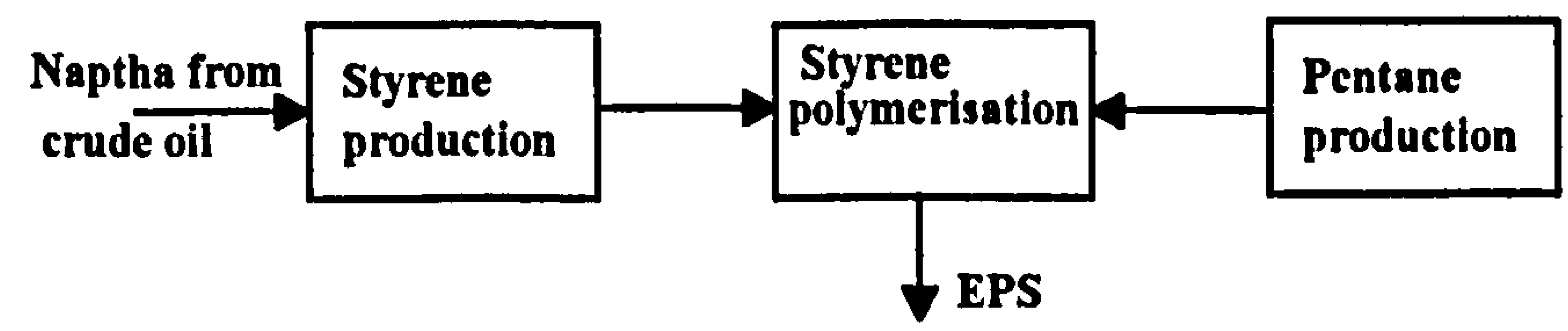
Air emissions	mg
Dust	5,590
CO	1,664
CO_2	2,996,700
SO_x	16,447
NO_x	14,470
HCl	209
HF	8
HC	22,045
CHO	5
Organics	5
Metals	2
CH_4	2,169
Hydrogen	1

Solid waste	mg
Mineral waste	77,050
Slags/ash	23,171
Industrial waste	3,354
Regulated chemicals	71
Unregulated chemicals	2,040

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 20 tonne payload, returning empty, average return distance 322 km

Appendix 82 Plastics and plastic products

Production and road delivery of expanded polystyrene (EPS) foam - per kg



Schematic flow diagram for the production of expanded polystyrene foam

Gross inputs and outputs associated with the production and bulk road delivery of expanded polystyrene (EPS) foam - per kg [1] Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	3.22
Electricity - delivered	1.36
Oil fuels - production & delivery	7.63
Oil fuels - delivered	25.62
Oil fuels - feedstock	28.03
Other fuels - production & delivery	4.74
Other fuels - delivered	17.03
Other fuels - feedstock	25.40
Total energy	113.01

Raw materials	mg
Barytes	4
Bauxite	1,835
Brine	52
Clay	21
Fe-Mn	76
Fluorspar	2
Iron ore	23,493
Lead	42
Limestone	8,374
Met coal	9,467
Water	11,067,400
NaCl	12,766
Air	1,440
Sulphur	95

Air emissions	mg
Dust	6,138
CO	8,269
CO_2	3,565,000
SO_x	152,783
H_2S	5
NO_x	53,215
HCl	46
F	1
HC	25,775
Metals	21
CH_4	374
Pentane	85,104

Primary fuels	MJ
Coal	3.39
Oil	30.66
Gas	24.30
Hydro	0.06
Nuclear	1.17
Total fuels	59.48
Primary feedstocks	**MJ**
Coal	0.31
Oil	27.81
Gas	25.08
Total feedstocks	53.20
Total fuels & feedstocks	112.68

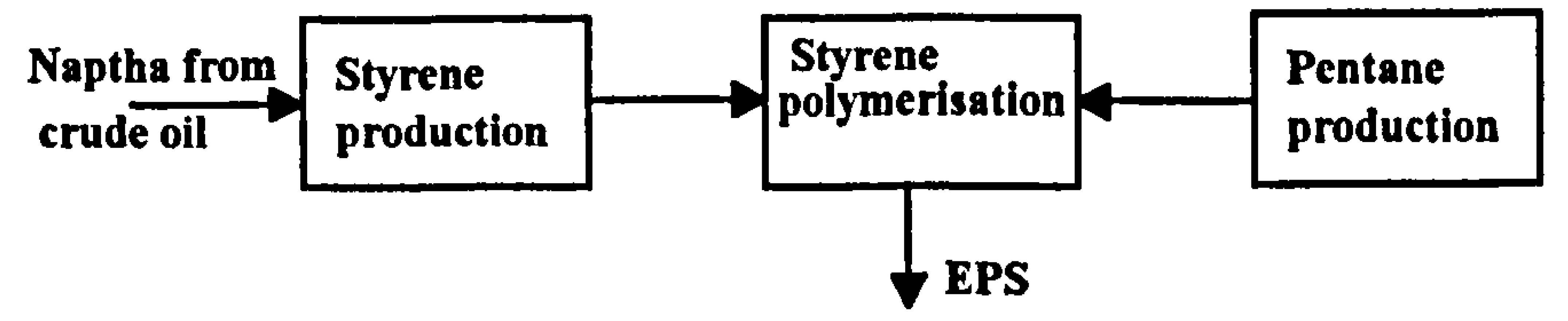
Water emissions	mg
COD	2,881
BOD	136
Acid	90
Metals	1,065
NH_4^+	426
Cl^-	106
Dissolved organics	340
Suspended solids	4,350
Detergent/oil	319
Hydrocarbons	647
Phenol	8
Dissolved solids	426
Other N	21

Solid waste	mg
Plastics	4
Organics	2
Mineral waste	46,422
Slags/ash	6,138
Industrial waste	3,737
Regulated chemicals	1
Unregulated chemicals	7,447

1 Polystyrene production data: I. Boustead, *Ecoprofiles of the European polymer industry*, APME Report No. 4, Polystyrene, May 1993.

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 480 kg payload, returning empty, average return distance 322 km

Production and road delivery of expanded polystyrene (EPS) foam insulation slab, 50 mm depth - per m^2



Schematic flow diagram for the production of expanded polystyrene foam slab

Gross inputs and outputs associated with the production and bulk road delivery of expanded polystyrene (EPS) foam insulation slab, depth 50 mm, - per m^2 Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	2.41
Electricity - delivered	1.02
Oil fuels - production & delivery	5.72
Oil fuels - delivered	19.21
Oil fuels - feedstock	21.02
Other fuels - production & delivery	3.56
Other fuels - delivered	12.77
Other fuels - feedstock	19.05
Total energy	84.76

Primary fuels	MJ
Coal	2.47
Oil	23.00
Gas	18.22
Hydro	0.04
Nuclear	0.88
Total fuels	44.61
Primary feedstocks	**MJ**
Coal	0.23
Oil	20.86
Gas	18.81
Total feedstocks	39.90
Total fuels & feedstocks	84.51

Raw materials	mg
Barytes	3
Bauxite	1,376
Brine	39
Clay	16
Fe-Mn	57
Fluorspar	2
Iron ore	17,620
Lead	32
Limestone	6,280
Met coal	7,100
Water	8,300,600
NaCl	9,574
Air	1,080
Sulphur	71

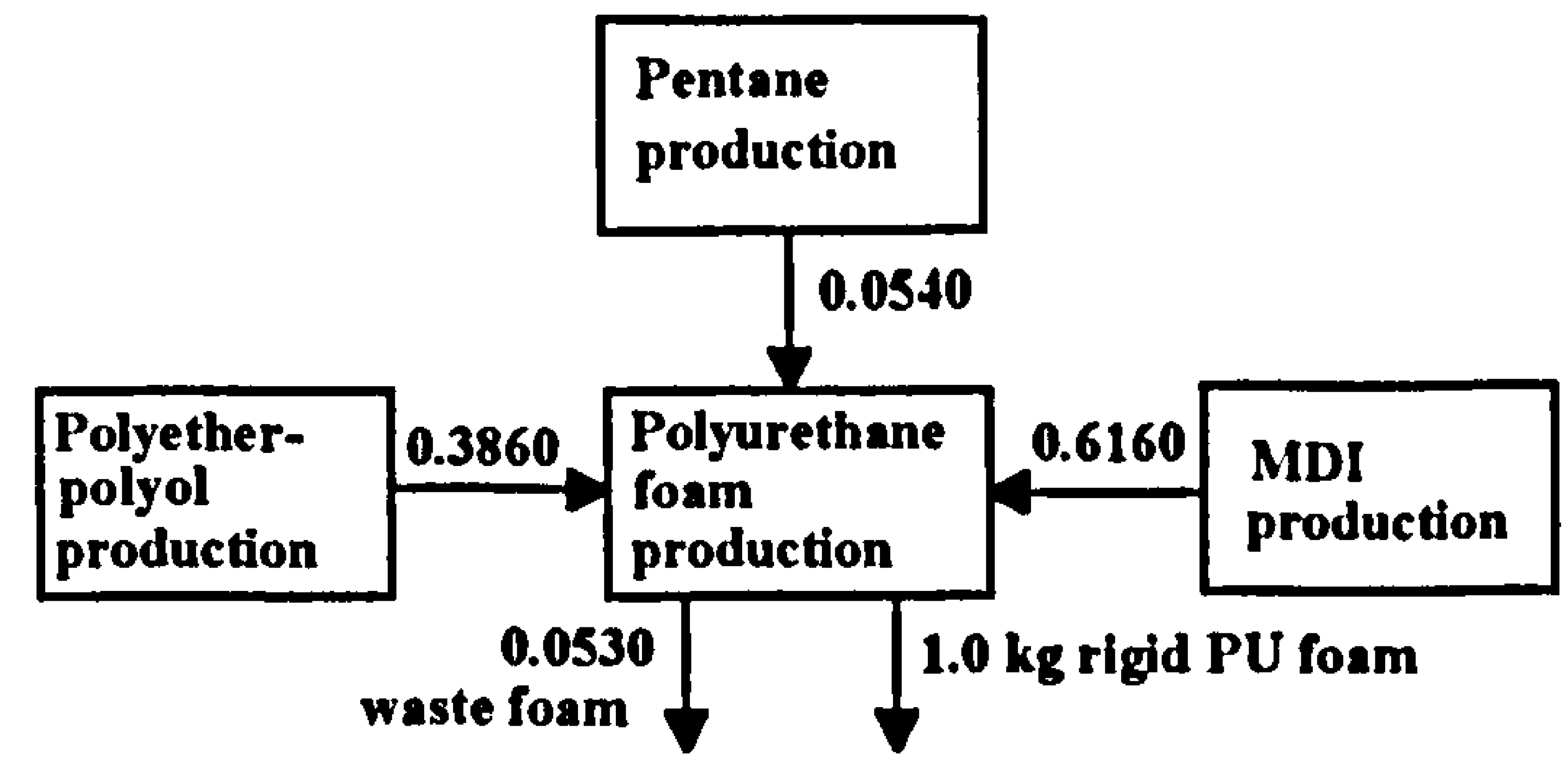
Water emissions	mg
COD	2,161
BOD	102
Acid	67
Metals	799
NH_4^+	319
Cl^-	80
Dissolved organics	255
Suspended solids	3,262
Detergent/oil	239
Hydrocarbons	485
Phenol	6
Dissolved solids	319
Other N	16

Air emissions	mg
Dust	4,604
CO	6,202
CO_2	2,673,700
SO_x	114,587
H_2S	4
NO_x	39,911
HCl	35
HC	19,331
Metals	16
CH_4	281
Pentane	63,828

Solid waste	mg
Plastics	3
Organics	2
Mineral waste	34,817
Slags/ash	4,604
Industrial waste	2,803
Unregulated chemicals	5,585

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): articulated vehicle, 480 kg payload, returning empty, average return distance 322 km

Production and road delivery of rigid polyurethane foam - per kg



Schematic flow diagram for the production of rigid PU foam. All flows are in kg (notional values)

Gross inputs and outputs associated with the production and road delivery of rigid polyurethane foam - per kg[1]

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	17.17
Electricity - delivered	7.27
Oil fuels - production & delivery	3.59
Oil fuels - delivered	9.07
Oil fuels - feedstock	16.25
Other fuels - production & delivery	5.20
Other fuels - delivered	25.46
Other fuels - feedstock	25.87
Total energy	109.87

Raw materials	mg
Bauxite	836
Brine	78
Fe-Mn	345
Fluorspar	11
Iron ore	106,610
Lead	2
Limestone	274,791
Met coal	43,345
Sand	943
Water	191,958,000
Phosphate	3,590
NaCl	874,692
Air	6,186
Sulphur as SO_2	54,781
Sulphur	3,344

Air emissions	mg
Dust	9,968
CO	2,936
CO_2	4,949,200
SO_x	40,270
H_2S	4
NO_x	23,328
NH_3	109
HCl	302
F	3
HF	11
HC	18,677
Organics	302
Metals	18
CH_4	1,641
H_2	590
Pentane	3,000
Organo- chlorine	120

Primary fuels	MJ
Coal	15.41
Oil	13.76
Gas	32.25
Hydro	0.30
Nuclear	6.02
Total fuels	67.73
Primary feedstocks	**MJ**
Coal	2.30
Oil	16.24
Gas	23.21
Biomass	0.39
Total feedstocks	42.13
Total fuels & feedstocks	109.86

Water emissions	mg
COD	5,966
BOD	1,081
Acid	182
NO_3^-	2,355
Metals	50,758
Cl^-	504,188
Dissolved organics	714
Suspended solids	41,459
Detergent/oil	60
Hydrocarbons	588
Organo-chlorine	81
Phenol	8
Dissolved solids	212
Other N	889
Na^+	30,985
SO_4^{2-}	7,943
Phosphate/P_2O_5	540

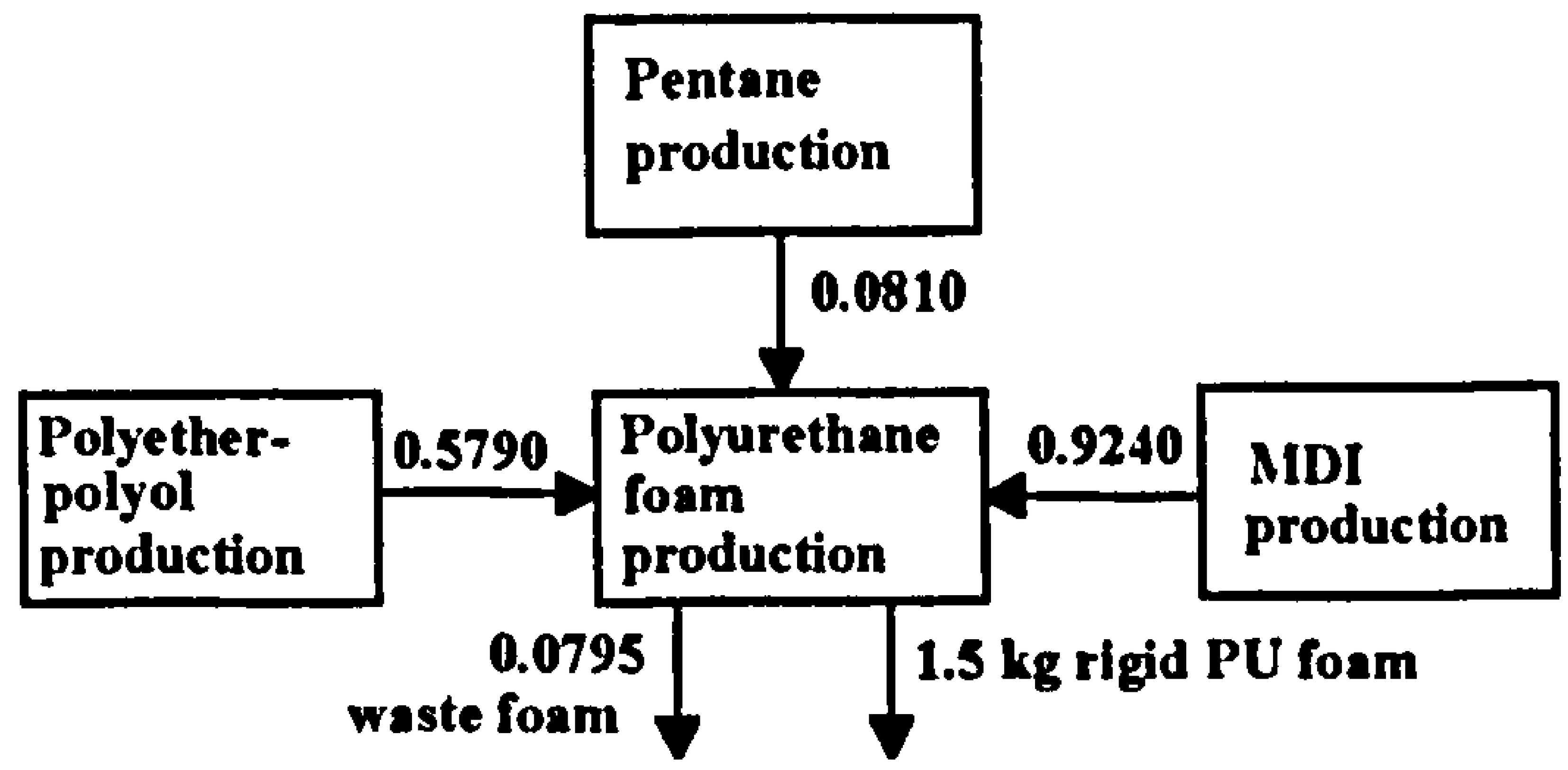
Solid waste	mg
Mineral waste	563,340
Slags/ash	45,292
Industrial waste	92,392
Regulated chemicals	3,229
Unregulated chemicals	5,605

1 MDI and polyol precursor production data: I. Boustead, *Ecoprofiles of the European plastics industry*, A Report for the European Isocyanate Producers Association (ISOPA), Polyurethane precursors (TDI, MDI, polyols), February 1996.

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): 15t rigid vehicle, 10t payload, returning empty, average return distance 200 km

Appendix 85 Plastics and plastic products

Production and road delivery of rigid polyurethane foam insulation, 50 mm depth - per m^2



Schematic flow diagram for the production of rigid PU foam. All flows are in kg (notional values)

Gross inputs and outputs associated with the production and road delivery of rigid polyurethane foam - per kg [1]

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	25.75
Electricity - delivered	10.91
Oil fuels - production & delivery	5.38
Oil fuels - delivered	13.61
Oil fuels - feedstock	24.37
Other fuels - production & delivery	7.80
Other fuels - delivered	38.19
Other fuels - feedstock	38.80
Total energy	164.81

Raw materials	mg
Bauxite	1,254
Brine	117
Fe-Mn	517
Fluorspar	18
Iron ore	159,914
Lead	2
Limestone	412,187
Met coal	65,018
Sand	1,415
Water	287,937,100
Phosphate	5,385
NaCl	1,312,000
Air	9,279
Sulphur as SO_2	82,171
Sulphur	5,015

Air emissions	mg
Dust	14,952
CO	4,404
CO_2	7,423,900
SO_x	60,405
H_2S	6
NO_x	34,992
NH_3	163
HCl	454
F	4
HF	16
HC	28,016
Organics	454
Metals	27
CH_4	2,461
H_2	884
Pentane	4,500
Organo- chlorine	181

Primary fuels	MJ
Coal	23.11
Oil	20.63
Gas	48.38
Hydro	0.45
Nuclear	9.03
Total fuels	101.60
Primary feedstocks	**MJ**
Coal	3.45
Oil	24.36
Gas	34.81
Biomass	0.58
Total feedstocks	63.19
Total fuels & feedstocks	164.79

Water emissions	mg
COD	8,948
BOD	1,621
Acid	273
NO_3^-	3,532
Metals	76,137
Cl^-	756,282
Dissolved organics	1,071
Suspended solids	62,189
Detergent/oil	90
Hydrocarbons	882
Organo-chlorine	122
Phenol	12
Dissolved solids	318
Other N	1,332
Na^+	46,477
SO_4^{-}	11,915
Phosphate/P_2O_5	811

Solid waste	mg
Mineral waste	845,010
Slags/ash	67,938
Industrial waste	138,588
Regulated chemicals	4,843
Unregulated chemicals	8,408

1 MDI and polyol precursor production data: I. Boustead, *Ecoprofiles of the European plastics industry*, A Report for the European Isocyanate Producers Association (ISOPA), Polyurethane precursors (TDI, MDI, polyols), February 1996.

Packaging & delivery: Bulk delivery, no packaging
Road transport (notional): 15t rigid vehicle, 10t payload, returning empty, average return distance 200 km

Appendix 86 Miscellaneous

Production and road delivery of pulverised fuel ash - per kg[47]

Coal → Coal combustion/ Power stations → Pulverised fuel ash

Schematic flow diagram for the production of pulverised fuel ash

Gross inputs and outputs associated with the production and road delivery of pulverised fuel ash - per kg

Totals may not agree because of rounding errors

Energy	MJ
Electricity - production & delivery	0.33
Electricity - delivered	0.14
Oil fuels - production & delivery	0.13
Oil fuels - delivered	0.87
Total energy	1.47

Raw materials	mg
Bauxite	2
Fe-Mn	1
Iron ore	310
Limestone	111
Met coal	128
Water	64,874
Air	19
Sulphur	1

Air emissions	mg
Dust	156
CO	103
CO_2	96,496
SO_x	1,394
NO_x	492
HCl	6
HF	1
HC	162
Metals	1
CH_4	89

Primary fuels	MJ
Coal	0.30
Oil	0.99
Gas	0.06
Hydro	0.01
Nuclear	0.11
Total fuels	1.46
Primary feedstocks	**MJ**
Total feedstocks	0.00
Total fuels & feedstocks	1.47

Water emissions	mg
COD	1
BOD	1
Acid	1
Suspended solids	46
Hydrocarbons	1
Phenol	1

Solid waste	mg
Mineral waste	2,464
Slags/ash	641
Industrial waste	108

Packaging & delivery: Bulk delivery, no packaging
Road transport: 24t articulated vehicle, 20t payload, returning empty, average return distance 161 km

Construction of a three bedroom bungalow and a four bedroom detached house - per building

Gross inputs and outputs associated with the construction of a bungalow and a detached house - per building

Totals may not agree because of rounding errors

Energy GJ	bungalow	house
Electricity - production & delivery	69.41	85.45
Electricity - delivered	29.89	37.05
Oil fuels - production & delivery	15.40	17.69
Oil fuels - delivered	77.00	103.04
Oil fuels - feedstock	30.01	19.20
Other fuels - production & delivery	20.35	24.94
Other fuels - delivered	206.09	253.88
Other fuels - feedstock	104.16	121.27
Total energy	552.30	662.52

Raw materials - g	bungalow	house
Barytes	39,995	55,821
Bauxite	29,204	53,001
Brine	548,661	705,377
$CaSO_4$	5,076,800	8,123,000
Chalk	3,577	6,064
Clay	54,984,300	68,858,000
Fe-Mn	2,416	3,088
Fluorspar	530	962
Iron ore	815,080	994,102
Lead	157,693	105,238
Limestone	99,960,400	97,004,400
Met coal	297,020	379,635
Sand	50,200,500	50,239,200
Tin	0	1
Water	330,050,300	367,149,000
Wood	7,396,600	9,033,200
Zinc	8,198	14,302
Copper	27,000	36,000
Phosphate	1,090	1,298
Shale	2,321,700	2,857,500
NaCl	18,071	33,663
Ulexite	15,660	10,980
Granite	23,490	16,470
Dolomite	99,522	111,006
Nitrogen	2,452	4,216
Air	203,574	268,737
Sulphur	13,251	17,512

Air emissions - g	bungalow	house
Dust	156,409	193,147
CO	53,279	69,993
CO_2	39,716,100	49,738,500
SO_x	312,146	403,472
H_2S	284	349
Mercaptan	2	3
NO_x	190,034	235,802
NH_3	1	1
HCl	6,875	8,554
F	59	97
HF	1,659	1,983
HC	74,840	91,526
Organics	10	15
Lead	1	1
Metals	38	58
CH_4	195,646	237,716
H_2	701	1,337
Pentane	12	20
Organo-chlorine	13	25

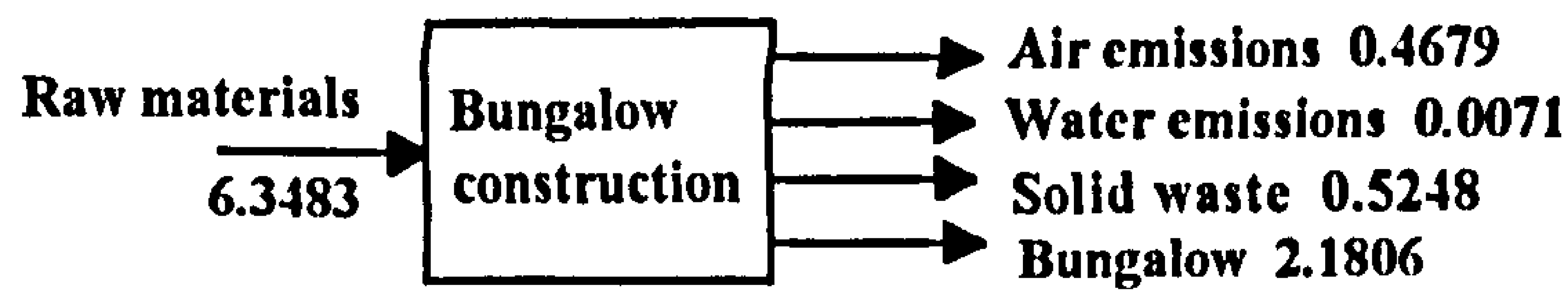
Primary fuels GJ	bungalow	house
Coal	167.08	205.82
Oil	97.65	127.67
Gas	120.38	145.32
Hydro	1.90	2.70
Nuclear	25.24	31.15
Lignite	0.01	0.01
Wood	5.63	8.94
Other	0.08	0.13
Sulphur	0.12	0.16
Recovered	-0.14	-0.18
Total fuels	417.95	521.70
Primary feedstocks GJ	**bungalow**	**house**
Coal	9.30	11.90
Oil	29.11	18.10
Gas	1.89	1.98
Wood	92.93	107.37
Biomass	0.18	0.22
Total feedstocks	133.42	139.55
Total fuels & feedstocks	551.37	661.26

Water emissions - g	bungalow	house
COD	2,050	2,573
BOD	309	374
Salt	58	64
Acid	459	579
NO_3^-	13	15
Metals	151	187
Cl^-	1,667	2,799
F^-	15	27
S	1	1
Dissolved organics	51	91
Dissolved solids	200	226
Suspended solids	609,786	927,472
Detergent/oil	6	7
HC	180	227
Phenol	110	124
Phosphorus	3	3
Other N	25	32
Na^+	133	244
SO_4^{2-}	44	78
Phosphate/P_2O_5	1	1
Other organics	2	3

Solid waste - g	bungalow	house
Plastic containers	623	964
Paper	118,571	149,761
Plastics	6,752	8,469
Metals	77,373	98,571
Organics	22,709	31,511
Other refuse	532,169	669,684
Mineral waste	25,166,300	29,722,700
Slags/ash	912,180	1,143,600
Industrial waste	11,745,700	11,631,000
Fired clay	7,075,200	8,873,800
Regulated chemicals	95	176
Unregulated chemicals	467	721

Appendix 88 Building construction

Construction of a three bedroom bungalow - per m² floor space



Schematic flow diagram for the production of a three bedroom bungalow
All flows are in tonnes per square metre of floor space

Gross inputs and outputs associated with the construction of a three bedroom bungalow - per m² floor space

Totals may not agree because of rounding errors

Energy	GJ
Electricity - production & delivery	0.80
Electricity - delivered	0.34
Oil fuels - production & delivery	0.18
Oil fuels - delivered	0.89
Oil fuels - feedstock	0.34
Other fuels - production & delivery	0.23
Other fuels - delivered	2.37
Other fuels - feedstock	1.20
Total energy	6.35

Raw materials	g
Barytes	460
Bauxite	336
Brine	6,307
$CaSO_4$	58,355
Chalk	41
Clay	632,004
Fe-Mn	28
Fluorspar	6
Iron ore	9,369
Lead	1,813
Limestone	1,149,000
Met coal	3,414
Sand	577,017
Water	3,793,700
Wood	85,019
Zinc	94
Copper	310
Phosphate	12
Shale	26,686
NaCl	208
Ulexite	180
Granite	270
Dolomite	1,144
Nitrogen	28
Air	2,340
Sulphur	152

Air emissions	g
Dust	1,798
CO	612
CO_2	456,507
SO_x	3,588
H_2S	3
NO_x	2,184
HCl	79
F	1
HF	19
HC	860
CH_4	2,249
H_2	8

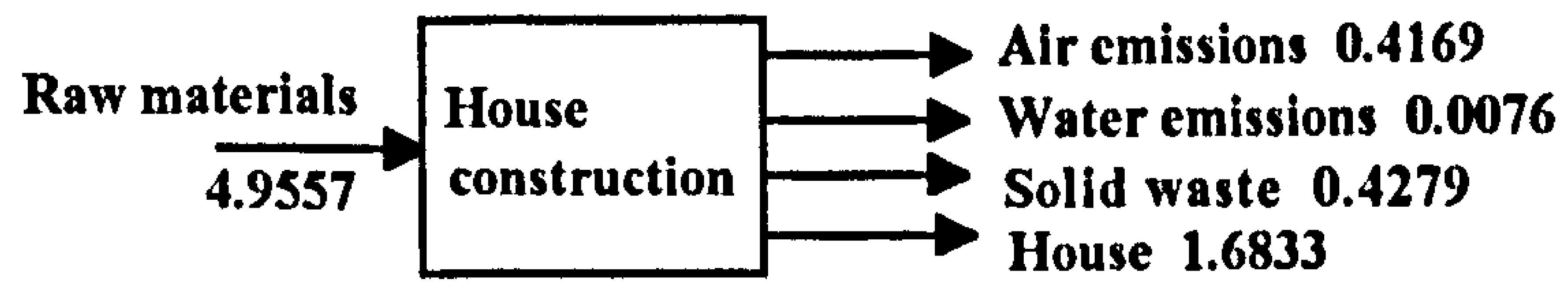
Primary fuels	GJ
Coal	1.92
Oil	1.12
Gas	1.38
Hydro	0.02
Nuclear	0.29
Lignite	0.00
Wood	0.06
Total fuels	4.80
Primary feedstocks	**GJ**
Coal	0.11
Oil	0.33
Gas	0.02
Wood	1.07
Total feedstocks	1.53
Total fuels & feedstocks	6.34

Water emissions	g
COD	24
BOD	4
Salt	1
Acid	5
Metals	2
Cl^-	19
Dissolved organics	1
Dissolved solids	2
Suspended solids	7,009
HC	2
Phenol	1
Na^+	2
SO_4^{2-}	1

Solid waste	g
Plastic containers	7
Paper	1,363
Plastics	78
Metals	889
Organics	261
Other refuse	6,117
Mineral waste	289,268
Slags/ash	10,485
Industrial waste	135,009
Fired clay	81,324
Regulated chemicals	1
Unregulated chemicals	5

Appendix 89 Building construction

Construction of a four bedroom detached house - per m² floor space



Schematic flow diagram for the production of a four bedroom detached house
All flows are in tonnes per square metre of floor space

Gross inputs and outputs associated with the construction of a four bedroom detached house - per m² floor space

Totals may not agree because of rounding errors

Energy	GJ
Electricity - production & delivery	0.70
Electricity - delivered	0.30
Oil fuels - production & delivery	0.15
Oil fuels - delivered	0.84
Oil fuels - feedstock	0.16
Other fuels - production & delivery	0.20
Other fuels - delivered	2.08
Other fuels - feedstock	0.99
Total energy	5.42

Raw materials	g
Barytes	456
Bauxite	433
Brine	5,768
$CaSO_4$	66,419
Chalk	50
Clay	563,025
Fe-Mn	25
Fluorspar	8
Iron ore	8,128
Lead	860
Limestone	793,168
Met coal	3,104
Sand	410,787
Water	3,002,000
Wood	73,861
Zinc	117
Copper	294
Phosphate	11
Shale	23,365
NaCl	275
Ulexite	90
Granite	135
Dolomite	908
Nitrogen	34
Air	2,197
Sulphur	143

Air emissions	g
Dust	1,579
CO	572
CO_2	406,692
SO_x	3,299
H_2S	3
NO_x	1,928
HCl	70
F	1
HF	16
HC	748
CH_4	1,944
H_2	11

Primary fuels	GJ
Coal	1.68
Oil	1.04
Gas	1.19
Hydro	0.02
Nuclear	0.25
Lignite	0.00
Wood	0.07
Total fuels	4.27
Primary feedstocks	**GJ**
Coal	0.10
Oil	0.15
Gas	0.02
Wood	0.88
Total feedstocks	1.14
Total fuels & feedstocks	5.41

Water emissions	g
COD	21
BOD	3
Salt	1
Acid	5
Metals	2
Cl^-	23
Dissolved organics	1
Dissolved solids	2
Suspended solids	7,584
HC	2
Phenol	1
Na^+	2
SO_4^{2-}	1

Solid waste	g
Plastic containers	8
Paper	1,225
Plastics	69
Metals	806
Organics	258
Other refuse	5,476
Mineral waste	243,032
Slags/ash	9,351
Industrial waste	95,103
Fired clay	72,558
Regulated chemicals	1
Unregulated chemicals	6

Appendix 90 Building construction

Construction of a three bedroom bungalow and a four bedroom detached house - per building

Revised gross inputs and outputs associated with the construction of a bungalow and a detached house - per building

Totals may not agree because of rounding errors

Energy GJ	bungalow	house
Electricity - production & delivery	65.31	80.53
Electricity - delivered	281.54	34.97
Oil fuels - production & delivery	16.22	18.42
Oil fuels - delivered	79.23	104.92
Oil fuels - feedstock	33.57	22.50
Other fuels - production & delivery	7.15	8.20
Other fuels - delivered	115.80	140.74
Other fuels - feedstock	109.00	126.29
Total energy	454.43	536.58

Raw materials - g	bungalow	house
Barytes	39,992	55,818
Bauxite	29,463	53,252
Brine	548,664	705,354
$CaSO_4$	5,198,800	8,284,900
Chalk	3,577	6,064
Clay	646,225	600,944
Fe-Mn	2,430	3,103
Fluorspar	530	962
Iron ore	816,926	995,746
Lead	157,670	105,208
Limestone	138,561,200	145,785,800
Met coal	297,736	380,266
Sand	53,988,900	56,267,000
Tin	1	1
Water	332,557,900	375,291,900
Wood	7,485,400	9,144,600
Zinc	8,200	14,306
Copper	27,000	36,000
Phosphate	1,090	1,298
Shale	2,667,000	3,315,600
NaCl	19,827	35,336
Ulexite	15,660	10,980
Granite	23,490	16,470
Dolomite	99,522	111,006
Nitrogen	2,452	4,216
Air	202,751	267,664
Sulphur	13,197	17,441

Air emissions - g	bungalow	house
Dust	143,911	177,951
CO	52,542	69,799
CO_2	31,692,800	39,757,400
SO_x	285,834	365,746
H_2S	325	404
Mercaptan	2	3
NO_x	129,990	158,804
NH_3	1	1
HCl	2,783	3,432
F	59	97
HF	294	270
HC	41,890	49,258
Organics	10	15
Lead	1	1
Metals	40	60
CH_4	79,801	92,865
H_2	701	1,337
Pentane	11,884	11,382
Organo-chlorine	13	25

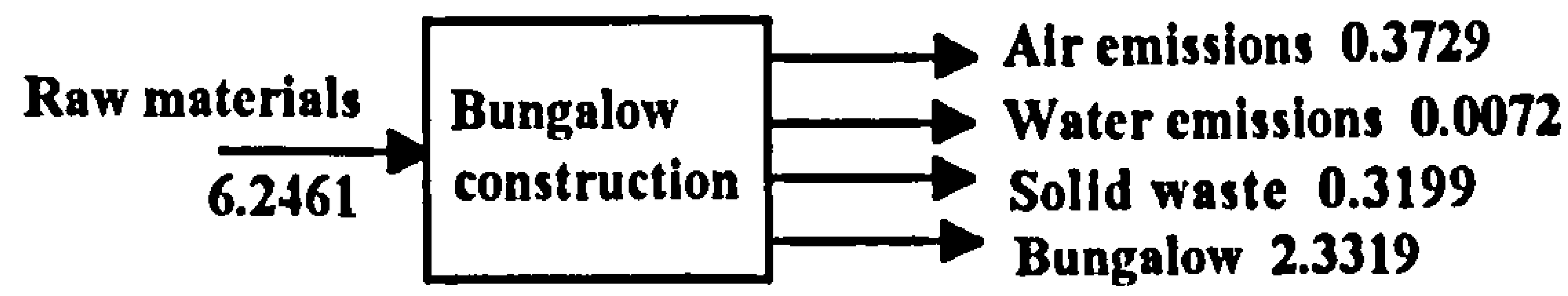
Primary fuels GJ	bungalow	house
Coal	139.28	171.80
Oil	99.12	128.45
Gas	42.26	46.49
Hydro	1.81	2.60
Nuclear	23.44	28.96
Lignite	0.01	0.01
Wood	5.63	8.94
Other	0.08	0.13
Sulphur	0.12	0.16
Recovered	-0.14	-0.18
Total fuels	311.61	387.36
Primary feedstocks GJ	**bungalow**	**house**
Coal	9.33	11.91
Oil	32.81	21.58
Gas	5.34	5.27
Wood	94.27	109.05
Biomass	0.18	0.22
Total feedstocks	141.93	148.03
Total fuels & feedstocks	453.55	535.39

Water emissions - g	bungalow	house
COD	2,291	2,755
BOD	326	389
Salt	58	64
Acid	317	398
NO_3^-	13	15
Metals	260	279
NH_4^+	60	57
Cl^-	1,678	2,809
F^-	15	27
S	1	1
Dissolved organics	98	136
Dissolved solids	258	282
Suspended solids	621,073	942,345
Detergent/oil	51	49
HC	266	307
Phenol	109	123
Phosphorus	3	3
Other N	28	35
Na^+	133	244
SO_4^{2-}	44	78
Phosphate/P_2O_5	1	1
Other organics	1	1

Solid waste - g	bungalow	house
Plastic containers	623	964
Paper	118,584	149,778
Plastics	1,938	2,422
Metals	89,141	113,339
Organics	22,708	31,509
Other refuse	603,844	759,627
Mineral waste	9,968,800	10,795,700
Slags/ash	181,795	226,608
Industrial waste	16,803,100	18,023,400
Fired clay	41,150	37,926
Regulated chemicals	95	176
Unregulated chemicals	1,466	1,665

Appendix 91 Building construction

Construction of a three bedroom bungalow - per m^2 floor space



Schematic flow diagram for the production of a three bedroom bungalow
All flows are in tonnes per square metre of floor space

Revised gross inputs and outputs associated with the construction of a three bedroom bungalow - per m^2 floor space Totals may not agree because of rounding errors

Energy	GJ
Electricity - production & delivery	0.75
Electricity - delivered	0.32
Oil fuels - production & delivery	0.19
Oil fuels - delivered	0.91
Oil fuels - feedstock	0.39
Other fuels - production & delivery	0.08
Other fuels - delivered	1.33
Other fuels - feedstock	1.25
Total energy	5.22

Raw materials	g
Barytes	460
Bauxite	339
Brine	6,306
$CaSO_4$	59,756
Chalk	41
Clay	7,428
Fe-Mn	28
Fluorspar	6
Iron ore	9,390
Lead	1,812
Limestone	1,592,600
Met coal	3,422
Sand	620,561
Water	3,822,500
Wood	86,038
Zinc	94
Copper	310
Phosphate	13
Shale	30,655
NaCl	228
Ulexite	180
Granite	270
Dolomite	1,144
Nitrogen	28
Air	2,331
Sulphur	152

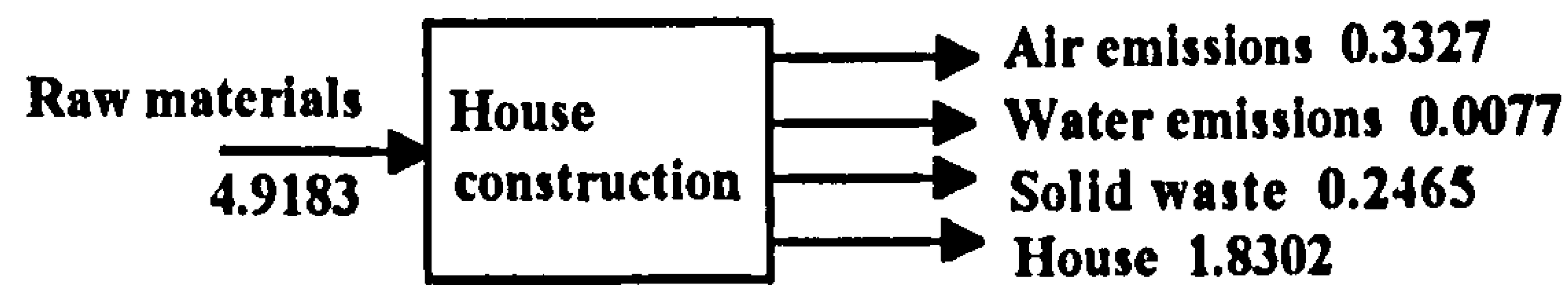
Air emissions	g
Dust	1,651
CO	604
CO_2	364,281
SO_x	3,284
H_2S	4
NO_x	1,494
HCl	32
F	1
HF	3
HC	481
CH_4	917
H_2	8
Pentane	137

Primary fuels	GJ
Coal	1.60
Oil	1.14
Gas	0.49
Hydro	0.02
Nuclear	0.27
Lignite	0.00
Wood	0.06
Total fuels	3.58
Primary feedstocks	**GJ**
Coal	0.11
Oil	0.34
Gas	0.06
Wood	1.08
Total feedstocks	1.63
Total fuels & feedstocks	5.21

Water emissions	g
COD	26
BOD	4
Salt	1
Acid	4
Metals	3
NH_4^+	1
Cl^-	19
Dissolved organics	1
Dissolved solids	3
Suspended solids	7,139
Detergent/oil	1
HC	3
Phenol	1
Na^+	2
SO_4^{2-}	1

Solid waste	g
Plastic containers	7
Paper	1,363
Plastics	22
Metals	1,025
Organics	261
Other refuse	6,940
Mineral waste	114,583
Slags/ash	2,090
Industrial waste	193,134
Fired clay	473
Regulated chemicals	1
Unregulated chemicals	17

Construction of a four bedroom detached house - per m² floor space



Schematic flow diagram for the production of a four bedroom detached house
All flows are in tonnes per square metre of floor space

Revised gross inputs and outputs associated with the construction of a four bedroom detached house - per m² floor space Totals may not agree because of rounding errors

Energy	GJ
Electricity - production & delivery	0.66
Electricity - delivered	0.29
Oil fuels - production & delivery	0.15
Oil fuels - delivered	0.86
Oil fuels - feedstock	0.18
Other fuels - production & delivery	0.07
Other fuels - delivered	1.15
Other fuels - feedstock	1.03
Total energy	4.39

Raw materials	g
Barytes	456
Bauxite	435
Brine	5,767
$CaSO_4$	67,742
Chalk	50
Clay	4,914
Fe-Mn	25
Fluorspar	8
Iron ore	8,142
Lead	860
Limestone	1,192,000
Met coal	3,109
Sand	460,074
Water	3,068,600
Wood	74,772
Zinc	117
Copper	294
Phosphate	11
Shale	27,111
NaCl	289
Ulexite	90
Granite	135
Dolomite	908
Nitrogen	34
Air	2,189
Sulphur	143

Air emissions	g
Dust	1,455
CO	571
CO_2	325,081
SO_x	2,991
H_2S	3
NO_x	1,299
HCl	28
F	1
HF	2
HC	403
CH_4	759
H_2	11
Pentane	93

Primary fuels	GJ
Coal	1.40
Oil	1.05
Gas	0.38
Hydro	0.02
Nuclear	0.24
Lignite	0.00
Wood	0.07
Total fuels	3.17
Primary feedstocks	**GJ**
Coal	0.10
Oil	0.18
Gas	0.04
Wood	0.89
Total feedstocks	1.21
Total fuels & feedstocks	4.38

Water emissions	g
COD	23
BOD	3
Salt	1
Acid	3
Metals	2
NH_4^+	0
Cl^-	23
Dissolved organics	1
Dissolved solids	2
Suspended solids	7,705
Detergent/oil	0
HC	3
Phenol	1
Na^+	2
SO_4^{2-}	1

Solid waste	g
Plastic containers	8
Paper	1,225
Plastics	20
Metals	927
Organics	258
Other refuse	6,211
Mineral waste	88,272
Slags/ash	1,853
Industrial waste	147,371
Fired clay	310
Regulated chemicals	1
Unregulated chemicals	14

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